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Snowfall and its Potential Management in the Semiarid Central Great Plains

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ABSTRACT

In 1955, investigations were initiated at the U.S. Central Great Plains Research Station, Akron, Colo., to monitor snowfall events, to estimate the contribution of snowmelt to crop production, and to design practical systems to trap and hold wind-transported snow for water conservation. For 24 winters, measurable snowfall occurred an average of 12 times per season, totaling 32 inches of cumulative snowfall, which contained 11.9 percent water and averaged 3.82 inches precipitation. Seasonal variations were sometimes extreme. Data are given for storm-size distribution, snowfall by months, snowfall during the nonfrozen soil period, and the characteristics of wind-transported snowfall.

Sufficient snowfall and water intake of snowmelt from drifted snow occurs to justify developing snow management systems. Snow management systems tested involved the use of short-height woodslat fences of various air porosities, grass production leeward of snow fencing, snow retention by vegetative barriers of crop stubble and perennial tall wheatgrass, and snow retention by stripcropping. Snow deposition by windbreaks was also noted. Snowmelt storage efficiencies in soil generally exceeded 60 percent.

The tall wheatgrass barrier system deposited snow onto crop target areas, significantly enhancing crop yields. This system should be adaptable to a large part of the Great Plains north of the 39° latitude where average annual snowfall exceeds 28 inches. Better snow control for both agricultural and nonagricultural areas, such as highways, is warranted.

KEYWORDS: Central Great Plains, crop stubble, snow, snowfall, snow fences, snowmelt intake efficiency, snowpack, vegetative barriers, windbreaks, wind-transported snow.

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SNOWFALL AND ITS POTENTIAL MANAGEMENT IN THE SEMIARID CENTRAL GREAT PLAINS

By B. W. Greb[1]

INTRODUCTION

Uncontrolled snow has long been a hazard of the northern and central Great Plains of the United States. Violent storms disrupt communication, power supply, and transportation. They also cause death and injury to human life, livestock, and wildlife. Yet, in favorable seasons, snowfall is a valuable water resource for stock ponds, range grasses, windbreaks, cropland, and recharge of ground water (*1*, *11*, *15*, *16*, *19*, *20*, *22*, *26*, *27*, *28*).[2]

Historically, snow management in the semiarid central Great Plains has received little research attention or technical assistance. Very few estimates exist regarding snow water losses to evaporation, sublimation, runoff, drifting onto nonuse sites, and deep percolation. Some resource data and limited experimentation, however, suggest agricultural productivity can be increased and service industries better protected by greater awareness of the characteristics of the snow and strategic planning to maximize its benefits. The magnitude of the snow resource available for manipulation depends upon (1) amount of snowfall, (2) distribution and duration of wind-transported snow, and (3) determination of the amount of snow needed for economic return.

This report includes the observation, experiences, snowfall statistics, and snow management experiments by and of the author at the U.S. Central Great Plains Research Station over a 24-year period, 1955 to 1979.

Snow Crystals

Research regarding snow crystal formation and shapes has been reported by Mason (*18*). Despite the infinite snowflake patterns, snow crystals are generally hexagonal and are classified into categories of star shape, leaf (plates), and columnar tubes either solid or hollow. Crystals are formed around very small nuclei particles. These particles are usually natural substances like volcanic ash, magnetite, kaolinite clay, and other natural dusts.

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[1] Soil scientist, Science and Education Administration, P.O. Box K, U.S. Central Great Plains Research Station, Akron, Colo. 80720.
[2] Italic numbers in parentheses refer to Literature Cited, p. 44.

These nuclei materials will activate crystal formation at temperatures ranging from 32° to -5°F.

Mason (*18*) reported a number of interesting phenomena involved with the natural production of snowfall as follows:

- In the atmosphere, snow crystals will fall at the rate of about one foot/second.
- Drop size is logarithmically related to temperatures, with small crystals being produced at lower temperatures.
- Decreasing temperatures logarithmically increase the number of atmospheric particles capable of acting as nuclei.
- Soil particles make up 75 percent of source material for nuclei.
- Kaolinite is the most abundant and active of natural atmospheric nuclei and is common to the Great Plains environment.
- Nuclei particles can be preactivated to initiate crystallization at higher temperature.
- Common montmorillonite clay is a poor nuclei material and needs extremely low temperatures to be active.
- Cloud seeding with iodides and oxides of several metals may induce greater snowfall. Often used in mountain regions.
- The natural dust load in the atmosphere of most agricultural regions is sufficient to activate snow crystallization.

The transition of atmospheric water in the form of snow to hail is difficult to define. Small porous particles of hail often take on the appearance of fused snow crystals. Hailstones large enough to damage crops are usually round ice particles exhibiting concentric rings.

Regional Snowfall Expectancy

In the semiarid central Great Plains, average annual snowfall ranges from 15 inches in Meade County, Kans., near the Oklahoma border, to 46 inches in Banner County in extreme western Nebraska (fig. 1). The snowfall increase in the north-northwest direction is a direct response to decreased temperatures as influenced by elevation and latitude. Annual temperatures decrease from 57°F in southwestern Kansas to 44°F near Cheyenne, Wyo. Likewise, the proportion of snowfall water to total annual precipitation increases from about 10 percent in Meade County to over 30 percent in Banner County. Within the area shown in figure 1, an estimated 7.6 and 7.1 million acre feet of snowmelt water are received annually on cropland and rangeland, respectively. As a water source for commercial crops, snowfall is more than double the value of rainfall because of much lower evaporation potential (*13*). Thus, in any water balance budget analysis, snowfall must be given this credit.

Snowfall in the semiarid central Great Plains varies greatly from season to season. Records at Holyoke, in northeastern Colorado, show annual snowfall

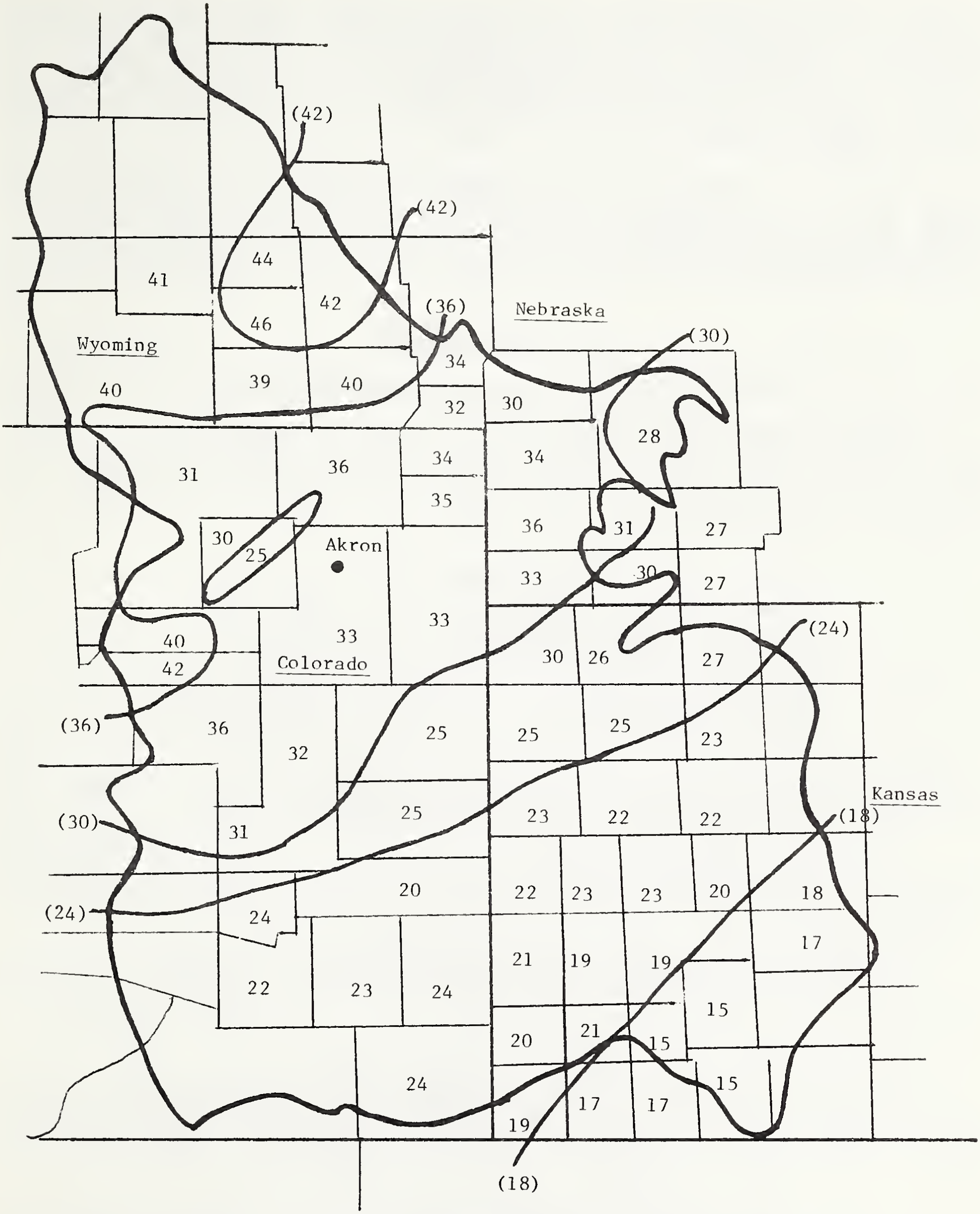

Figure 1.--Mean annual snowfall (inches) in the semiarid central Great Plains (*25*).

ranging from 16 to 146 inches (*25*). Within Washington County, Colo., annual snowfall has ranged from 10 to 128 inches. Since World War II, the high snowfall seasons throughout much of the region include the winters of 1946-47, 1948-49, 1956-57, 1972-73, and 1973-74. Despite the extreme year-to-year variation, snowfall data in figure 1 do show a logical pattern of snowfall expectancy across the region.

Any system designed for snow management must account for and adjust to a number of snowfall characteristics imposed by climatic, soil factors, and vegetative factors that influence seasonal distribution, wind-transported snow, quantities of snow, water content, retention by obstructions, and soil water intake of snowmelt.

MONITORING SNOWFALL

Description of Area and Snow Monitoring Criteria

The U.S. Central Great Plains Research Station, Akron, Colo., is located approximately 120 miles east of the Rocky Mountains in Washington County, 40.1° N. latitude and 103.1° W. longitude, at 4,538 feet elevation. The climate is distinctly cool-semiarid (*13*). Some climatic statistics, as recorded at the Station since 1911, include:

Annual precipitation................	16.25 inches
Seasonal snowfall expectancy........	32.0 inches
Mean annual temperature.............	48.5°F
Mean January temperature............	25.0°F
Mean July temperature...............	73.5°F
Average wind velocity...............	6.6 miles/hour
Average frost-free season...........	144 days

The upland topography is nearly level for great distances and offers little interference to wind movement and wind-transported snow.

Monitoring snowfall at the station has included recording the number of snowstorm events per season, days of snowfall received per season, date and amount of level snow, snow water content, and snowdrifting (*10*, *11*).

An official snowstorm was recorded if the snowfall deposited 0.5 inches or more in a 24-hour period. Intermittent snowfall deposited without a 24-hour interruption was considered a single event, even if it continued to deposit snow for two or more consecutive days.

All tests at the Akron station, involving soil moisture samples for snowmelt and water-use efficiency by plants, were conducted on Rago silt loam (Pachic Arguistoll) and Welt silt loam (Aridic Paleustoll). These soils have similar depths (over 7 feet) and water holding capacities.

Level Snowfall

Because the physical nature of snow and its manner of falling vary considerably, new snowfall depths were estimated within broad limits of ±0.5

inches with a yardstick. About 36 percent of all events had wind velocities that caused snowdrifting. Thus, obtaining a reasonable measure for level snow, at or near the unprotected weather recording station, was sometimes difficult. Whenever strong or very strong (>20-mile/hour(mi/h) wind) drifting occurred, snow depths were measured in a protected area within the town of Akron, 4 miles west of the Station. At least six samples were taken per storm on hard surfaces for snow depth and water content.

Because once or twice each season, cold rain turned to snow or a wet snow partially melted upon contact with warm surfaces, snow depth measurements were proportional estimates. Amounts of snowfall recorded for single events varied from 0.5 to 20 inches during 1955 to 1979.

In northeastern Colorado and Akron, snowfall accumulated into a well-defined snowpack (from fall to spring) only 3 of the last 24 winter seasons and 5 of the last 42 years or about 12 percent of the winters. Consequently, certain snow management must account for snow disappearance by melting between storms in the central Great Plains. In the northern Great Plains, however, snowfall tends to build a permanent snowpack most of the winter seasons.

Snow Precipitation

Although standard U.S. weather shielded rain gages improved the precision of measuring wind-transported rainfall by 50 percent, the precision for snowfall was only improved 30 to 40 percent (*6*). Therefore, this author used a simple core sampling device to obtain the volume weight of new snow in this study. The core sampler was a copper tube 12 inches long with a 3-inch inside diameter (I.D.). Depth markings were etched at 2-inch intervals on the outside (*10*). Narrow vertical slots were cut through the side of the tube to release air pressure and permit visual inspection for the proper filling of snow in the tube without compression. A plunger inside the tube was used to push snow samples into metal cans with airtight lids for weight determination.

Most samples contained from 1 to 4 inches of snow. The driest snow ever recorded was from a 3-inch snowfall with 4-percent water content in January. The wettest snow occurred during wet blizzards, with up to 20- to 22-percent water content of level snow.

The snowfall data revealed that water content of new snow was related to air temperatures and wind velocity (fig. 2). Under nonwind conditions, the water content of new snow on the ground ranged from about 5.5 percent at 0°F to 17 percent at 35°. At windspeeds of 20 to 30 mi/h, water content for new snow ranged from about 9 percent at 0° to 22 percent at 35°.

Snow precipitation data obtained by snow core sampling were compared with those from a shielded rain gage during the winters of 1955-56 to 1978-79, involving 288 snowfall events. Snow precipitation during this period averaged 3.82 inches per season by core sampling and 2.50 inches per season by rain gage measurement. The error by rain gage varied from 13 to 58 percent and averaged 35 percent per season. This same error likely exists at nearly all other

recording weather stations in the central and northern Great Plains. I estimate that, for Great Plains locations exceeding 20 inches of snowfall annually, total precipitation being measured is short by 0.6 to 1.5 inches per season.

The difficulty with rain gages involves deflected air currents and air pressure in the vicinity of the gage, which tend to reject snowflakes. Also, high windspeeds carry snowflakes at a low angle or almost horizontally across the gage orifice. A relationship of windspeed to snow catchment by a shielded gage was worked out by Cox and Hamon (*6*). They showed that the percentage of snow catchment by a shielded gage decreased rapidly with increased windspeed during snowstorms.

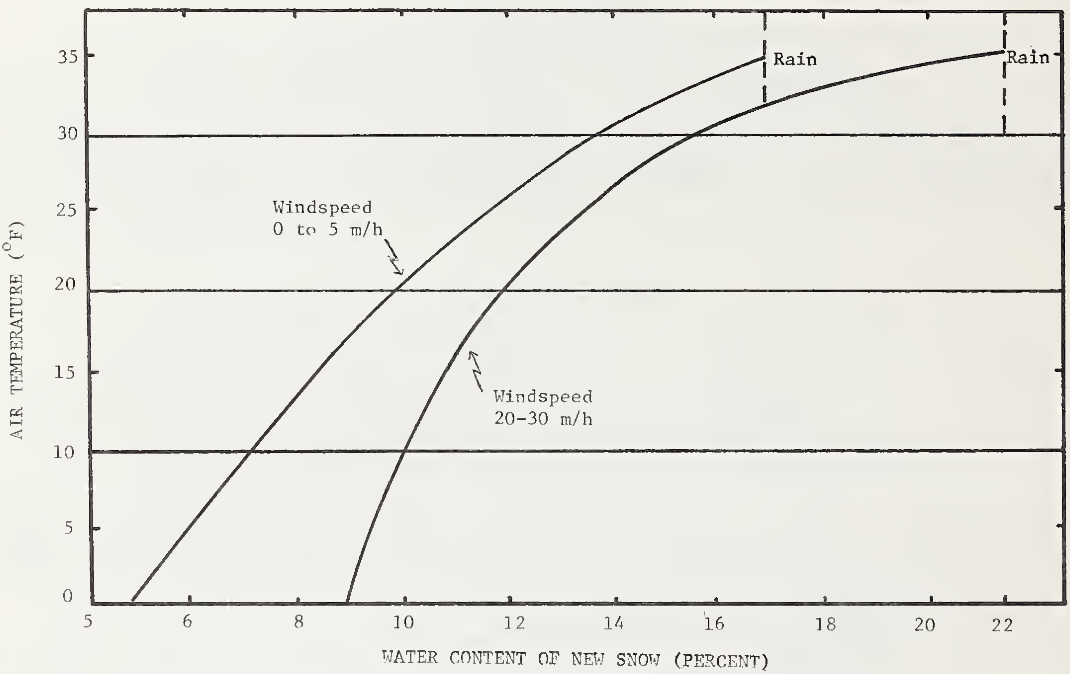

Figure 2.--General relationship of water content of new snowfall at given air temperatures at Akron, Colo., interpolated from 288 snowfall events (*11*).

CHARACTERISTICS OF SNOWFALL AT AKRON

Snowfall Statistics

Annual Snowfall

During 24 winter seasons, 1955-56 to 1978-79, the number of officially recorded snowfall events averaged 12 per season but varied widely from 4 events in the winter of 1971-72 to 23 events in both 1972-73 and 1973-74 (table 1). Days that snow was received varied from 4 to 34 and averaged 14 per season.

For 15 consecutive years, 1955-56 to 1969-70, snowfall events were reasonably consistent at 9 to 13 per season. During this same period, days that snowfall was received varied from 9 to 17 per season.

Annual snowfall varied from 11 to 82 inches per season, and averaged 32 inches per season. Five seasons received less than 20 inches of snow, and three seasons had greater than 60 inches. About 67 percent of the winter seasons received less than average snowfall. The least amount of snowfall for an extended period of years occurred from the 1961-62 winter season through 1968-69 with an average of only 21 inches per season recorded. Despite the dry winter of 1971-72, the period from 1969-70 through 1973-74 averaged 49 inches of snowfall per season. There were four seasons with nearly average snowfall, occurring in 1958-59, 1963-64, 1975-76, and 1976-77. Annual snowfall is known to be highly erratic in the cooler portions of the Great Plains north of 39° latitude. Thus, the snowfall data recorded at Akron appear typical.

Water Content and Snow Precipitation

Water content of new snow generally ranged from 7 to 15 percent. Water content each season ranged from about 9 to 14.3 percent (table 1). The average water content for snow for all seasons was 11.9 percent, which is somewhat higher than the 8 percent average recorded in high mountains (*11*). In the mountains, snowfall is usually received under consistently cooler air temperatures and is thus lower in average water content (fig. 2). Likewise, the average water content of new snow by seasons at Akron varied according to the number and amount of drier snows received during the coldest months in proportion to the number and amount of wetter snows received during the fall and spring months.

Snowfall precipitation ranged from 1.42 inches of water in 1971-72 to 11.73 inches the following year (table 1). Snow precipitation averaged 3.82 inches per season for all 24 seasons recorded. In five winters, less than 2 inches per season of snowfall water was received, and more than 5 inches per season was received in 5 other years. During 12 consecutive years, 1957-58 to 1969-69, snow precipitation averaged 2.71 inches per season; whereas during the last 10 years, snow precipitation has averaged 4.95 inches per season. This suggests the probability that long term snowfall has low and high cycles in number and amount of precipitation received.

Snowfall Per Storm

Individual snowfall events were divided into categories of 1, 2, 3, 4, and 5 or more inches of snowfall per storm (table 2). Of 288 storms recorded, storms with a 1-inch deposit comprised 43 percent of all storms, averaged 9.7-percent water content, and contributed 13 percent of all snow precipitation. The 2-inch storms comprised 20 percent of all storms with an average of 10.7-percent water content and 14 percent of snow precipitation received. Both the 1- and 2-inch storms were usually more frequent from December to early March under cold air conditions and less wind movement. Storms of 3 and 4 inches of snow comprised 24 percent of all storms and contributed 32 percent of total snow precipitation. Storms of 5 inches or more comprised only 13 percent of all storm events and averaged 12.7-percent water content. These storms, although infrequent, contributed 41 percent of all snow precipitation and

Table 1.--*Precipitation during 24 winter seasons at Akron, Colo.*

Winter season	Snowfall events	Days snowfall received	Season snowfall	Water content[1]	Water from snowfall
	Number	*Number*	*Inches*	*Percent*	*Inches*
1955-56	10	11	18	9.0	1.62
1956-57	13	17	70	12.5	8.77
1957-58	11	12	22	9.5	2.08
1958-59	12	14	31	11.0	3.59
1959-60	12	13	39	9.0	3.50
1960-61	10	11	28	13.0	3.65
1961-62	9	10	19	9.1	1.73
1962-63	9	9	21	11.9	2.50
1963-64	10	10	30	12.5	3.75
1964-65	9	9	21	10.8	2.26
1965-66	9	9	21	12.6	2.64
1966-67	11	12	20	14.2	2.84
1967-68	12	12	21	11.0	2.30
1968-69	10	10	16	10.6	1.70
1969-70	11	14	46	11.6	5.66
1970-71	15	19	39	10.7	4.16
1971-72	4	4	11	12.9	1.42
1972-73	23	34	82	14.3	11.73
1973-74	23	28	67	12.1	8.11
1974-75	12	14	24	14.1	3.38
1975-76	13	15	31	10.5	3.26
1976-77	11	12	32	14.0	4.48
1977-78	12	12	14	12.0	1.68
1978-79	17	20	46	12.2	5.63
Average	12	14	32	11.9	3.82

[1] Determined by core sampling of new snow per event.

generally occurred in October and November and again from late March to early May. These storms were usually caused when large frontal northward movements of warm moist air from the Gulf of Mexico collided with masses of cold Canadian air moving southward.

Snowfall by Months

Snowfall was recorded at least once for the months September through May during the 24-year recording period (table 3). Earlier station records at Akron show that snowfall occurred twice in June and three times in September during 1908 to 1955. The snow season usually extends from October 20 through April 15. Snowfall received per month, during the 24 recording years, occurred over 90 percent of the seasons for December, January, and March. Snowfall in February occurred only 67 percent of the winter seasons; however, in some years February had several small storms in rapid succession.

Table 2.--*Size distribution and water content of snowfall events during 24 winter seasons at Akron, Colo., 1955-56 to 1978-79*

Snowfall per event (inches)	Total storms	Events category	Snowfall category	Average water content	Precipitation by category
	Number	*Percent*	*Percent*	*Percent*	*Percent*
1	124	43	16	9.7	13
2	59	20	15	10.7	14
3	42	15	16	12.4	17
4	27	9	14	12.5	15
>5 [1]	38	13	39	12.7	41
Total or average	288	100	100	11.9	100

[1] Averaged 7.7 inches snowfall per storm.

Table 3.--*Snowfall by months during 24 winter seasons at Akron, Colo., average of 1955-56 to 1978-79*

Month	Total events	Probability	Events per month	Snowfall per month	Snowfall per event	Water content	Snow precipitation per month
	Number	*Percent*	*Number*	*Inches*	*Inches*	*Percent*	*Inches*
Sept.	1	4	---	0.2	---	---	0.03
Oct.	17	50	0.7	2.8	4.0	13.9	.39
Nov.	33	70	1.4	5.1	3.7	13.1	.67
Dec.	48	96	2.0	3.6	1.8	11.4	.41
Jan.	51	92	2.1	5.1	2.4	9.2	.47
Feb.	46	67	2.0	3.4	1.7	10.3	.35
Mar.	63	96	2.6	7.2	2.7	11.8	.84
Apr.	24	54	1.0	3.8	3.8	14.2	.54
May	5	12	.2	.8	3.9	16.1	.12
Total or average	288		12.0	32.0	2.7	11.9	3.82

Note: Dashes indicate no data.

An average of two or more storms per season occurred during December to March with the highest frequency of 2.6 storms per month occurring in March. In terms of average snowfall per month, November and January averaged 5.1 inches with March the highest at 7.2 inches. Snowfall in the remaining cooler seasons months ranged in depth from 2.8 to 3.8 inches.

The average water content of new snow per month was highest during October (13.9 percent) and April (14.2 percent) and lowest in January (9.2 percent) and February (10.3 percent). The water content of new snow correlated well with mean monthly temperatures, especially for January to May (fig. 3).

The highest snowfall precipitation per month was 0.84 inch in March, and the next highest was 0.67 inch in November. The lowest snow precipitation from October to April occurred during February with only 0.35 inch per season.

Snowfall During Nonfrozen Soil Period

The soil at Akron is usually frozen from about December 11 to February 20 (table 4). During this period, about 33 percent of the total snowfall is received. The drier-type snow normally occurring during this period contributed only 27 percent of snow precipitation. Thus, about 73 percent of the total snow precipitation occurs during nonfrozen soil conditions. This is an important factor in the recharge of available soil water on cropland and rangelands in the central Great Plains (*11*, *15*, *16*). Because of the preponderence of nonfrozen soil during the snow season, soil erosion from snowmelt at Akron is minimal and soil water storage potential is high.

Wind-Transported Snowstorms

Snowfalls at Akron have occurred with windspeeds ranging from 0 to greater than 80 mi/h. Significant snowdrifting involved at least 2 inches snowfall with wind velocities above 12 mi/h during a given storm (table 5). Snowdrifts exceeding 8 feet in height have been recorded during blizzards in which the undisturbed level snow depth was only 5 inches. Snowdrift formations on large open pastures are associated with irregular topography such as the lower end of south slopes and sharp drainage bottoms. Snowdrifts are also associated with obstructions such as fences, trees, crop stubble, weed clumps, and buildings. Snow movement was also related to the density of the ice crystals. Wet snow moved less at a given windspeed than dry snow. In this case, wet snow means new fallen snow containing 14-percent water content or greater.

Wind-Transported Snow Statistics

Snowstorms causing snowdrifts greater than 12 inches deep occurred 103 times during the 24-year recording period, averaging 4.3 times per season (table 6) or 36 percent of all snowfall events. There were two seasons without drifting and two that had eight drifting events, but most seasons had three to six events.

Snowfall received under drifting conditions averaged 16.5 inches per season, which accounted for 52 percent of all snowfall. Snowfall deposited per

Table 4.--*Snowfall during the frozen and nonfrozen soil period at Akron, Colo., average of 1955-56 to 1978-79*

Seasonal period	Snowfall	Precipitation	Snowfall per season	Snow precipitation per season
	Inches per season	*Inches per season*	*Percent*	*Percent*
Fall[1]	9.3	1.19	29	31
Spring[2]	12.1	1.59	38	42
Total, nonfrozen period	21.4	2.78	67	73
Winter[3]	10.6	1.04	33	27
Seasonal total	32.0	3.82	100	100

[1]Nonfrozen soil, Sept. 1 to Dec. 10.
[2]Nonfrozen soil, Feb. 21 to May 11.
[3]Frozen soil, Dec. 11 to Feb. 20.

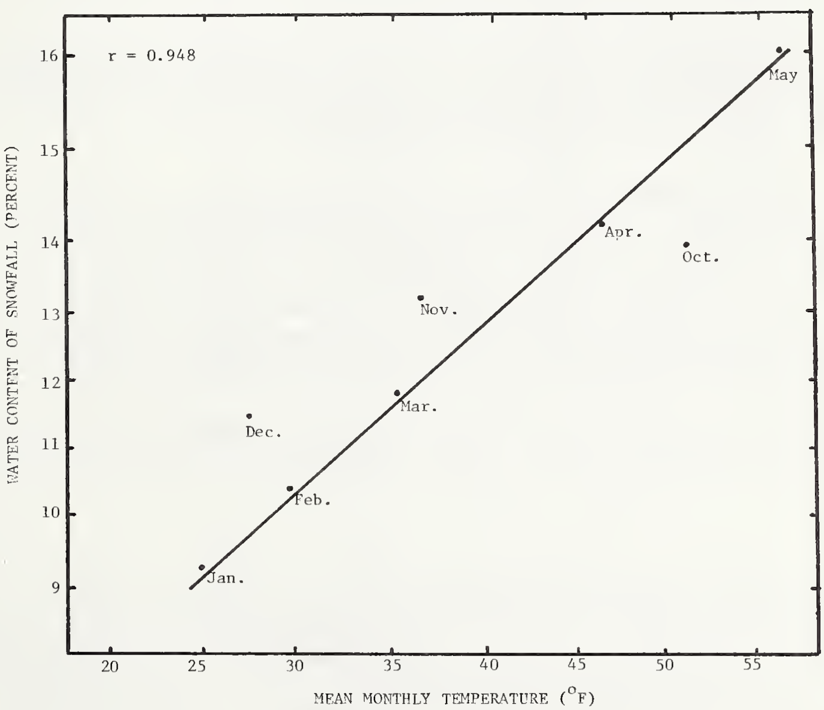

Figure 3.--Relationship of new snowfall water content and mean monthly temperatures at Akron, Colo., average of 24 winter seasons, 1955-56 to 1978-79.

Table 5.--*Categories of wind-transported snowfall at peak wind velocities as measured at 48 inches above ground level at Akron, Colo.*

Wind velocity (miles per hour)	Type snow movement	Relative snowdrifting
0-5	None	None
5-12	Surface creep, localized	Slight.
12-20	Surface creep, general	Moderate.
20-35	Turbulent diffusion some airborne	Strong.
>35	General airborne, near zero visibility	Very strong.

drifting storm averaged 3.8 inches as compared with only 2 inches for nondrifting storms. A significant number of drift-producing storms were the higher water content wetter snows received during the fall and spring months; fewer drift-producing storms occurred during the midwinter period. An unknown parameter at Akron is the total movement of blowing snow during snowfall events and between these events (ground blizzards).

Level snow deposited during drifting storms averaged 13.1 percent water content as compared with 10.7 percent for all nondrift storms (table 6). Thus, with greater snowfall per storm and a higher water content, drifting storms produced 57 percent of all snowfall precipitation.

Drifting snow causes sintering and abrasion of ice crystals into smaller particles, which pack into a denser state than undisturbed level snow. For the years listed at Akron, the newly formed drifts averaged 19.8-percent water content or were 1.5 times as dense as adjacent level snow (table 6). In general, the water content of the surface layers of a new drift was also slightly greater than that in the middle or bottom of the drift. Upon ripening,[3] this would reverse, and the denser snow would be on the bottom of the drift.

Drifting snow offers a possibility for snow management to increase water conservation on cropland sites. This potential will be discussed in following sections.

Blizzards

A full scale blizzard in the Great Plains is highly dangerous to people and property. Although the snowfall from blizzards may have some water recharge benefit, the snow is usually stockpiled in ditches, rights-of-way, and leeward of any major obstructions such as buildings and windbreaks. Whole communities or even several counties are sometimes isolated for several days

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[3] Drift setting caused by warm temperatures.

Table 6.--*Wind-transported snowstorms at Akron, Colo., 1955-56 to 1978-79*

Winter season	Wind-transported snowstorms	Snowfall[1]	Snow precipitation	Water content: Nondrifted	Water content: Drifted	Drifted level
	Number	*Inches*	*Inches*	*Percent*	*Percent*	*Ratio*
1955-56	4	7	0.75	10.7	([2])	([2])
1956-57	6	45	6.67	14.8	([2])	([2])
1957-58	5	13	1.29	10.0	([2])	([2])
1958-59	6	21	2.73	13.0	([2])	([2])
1959-60	6	25	2.41	9.6	16.7	1.7
1960-61	5	18	2.19	12.2	16.0	1.3
1961-62	3	12	.91	7.9	21.8	2.8
1962-63	6	14	1.71	11.4	18.2	1.6
1963-64	5	22	3.17	14.4	18.0	1.3
1964-65	3	12	1.34	11.2	18.9	1.7
1965-66	3	8	1.19	14.9	20.6	1.4
1966-67	4	12	2.13	17.7	22.8	1.3
1967-68	5	14	1.72	11.9	15.6	1.2
1968-69	3	6	.90	15.0	22.6	1.5
1969-70	4	26	3.53	13.6	20.9	1.5
1970-71	5	17	1.73	10.2	20.1	2.0
1971-72	0	0	0	--	--	--
1972-73	8	49	7.35	15.2	22.7	1.5
1973-74	8	30	3.95	13.0	19.9	1.5
1974-75	2	7	1.11	15.8	17.4	1.1
1975-76	6	17	2.13	12.5	23.0	1.8
1976-77	3	10	1.56	15.6	24.2	1.6
1977-78	0	0	0	--	--	--
1978-79	3	11	1.33	12.1	16.5	1.4
Average	4.3	16.5	2.16	13.1	19.8	1.5
Nontransported snow	7.7	15.5	1.66	10.7	--	--
Transported snow as percentage of total	36	52	57	--	--	--

[1] Measured in nonwind transport areas.

[2] Not measured.

Note: Dashes indicate no data.

before transportation can be resumed. Power poles are particularly vulnerable to breakage during wet blizzards. The ice load on a single telephone wire reached 7 lb/linear foot on March 10, 1977, as reported by the Y-W Electric Company of Akron.

A blizzard as defined here, is any given storm in excess of 4 inches of snowfall, 35 mi/h wind velocities, and 8 hours duration. The temperature factor is not included. Whenever these criteria are met, the results are near zero visibility and a sufficient chill factor to be hazardous to people, livestock, poultry, and wildlife.

During the last 31 years at Akron, 27 blizzards have occurred (table 7). These blizzards averaged 7.7 inches of snowfall and 0.97 inch of precipitation per event. There is a 65-percent probability (based on 31 years of record) that Akron will receive at least one blizzard or more per winter (table 8). Blizzards have been recorded at Akron for the cooler months, October through May. Of the 27 blizzards recorded since 1949, six occurred in November and five each in January and February (table 9).

The greatest single blizzard occurred January 2-4, 1949 (table 7). This storm paralyzed much of the Western United States from Nevada to Iowa, and the toll in human life was high. An estimated 37 people lost their lives in the area bounded by Kimball, Nebr., Cheyenne, Wyo., and Ault, Colo. Some of these casualties included students returning to college after the holiday season. Other memorable and destructive storms include November 2-3, 1956, March 27-28, 1975, and March 10, 1977.

The storm of March 10, 1977, was the strongest wind-driven snow in the history of the Akron Station. Wind velocities were recorded at 93 mi/h for 14 hours near Cope, 45 miles southeast of Akron. At the Station, wind gusts of over 80 mi/h were recorded. The damage to power poles and lines in eastern Colorado was estimated by the Y-W Electric Company at $7.2 million. The wind was so violent that even standing crop stubble could stop very little snow. Only buildings, multiple-row dense windbreaks, roadside ditches, and steep creek bottoms stopped snow movement. The town of Akron and the Station headquarters area were buried in drifts 4 to 12 feet deep. Numerous photographs were taken to record anticipated and freakish snow deposition patterns. The large north-south windbreaks at the Station suffered extensive damage to 25- to 30-foot-tall 41-year-old Ponderosa pine (*Pinus ponderosa* Dougl. ex P. and C. Lawson) with some tree trunks snapped off and leeside branches broken at 10- to 14-foot heights. A few of the pines were bent over and completely buried by snow. Measurements of the new drifts showed 34.6-percent water equivalent, which was 3 percent higher than any previous recorded snowdrift since core sampling began. The only snow held in the field at the Station was leeward of tall wheatgrass barriers where the snow was deposited to an average 10.8-inch depth, which contained 3.75 inches water equivalent. The day after the storm subsided, a tour southeast of Akron showed very little snow for the first 3 to 4 miles. It appeared that the town acted as a huge trap to desaturate the airborne snow load.

Table 7.--*Blizzard events during 31 winter seasons at Akron, Colo., defined as >4 inches of snowfall with windspeeds >35 mi/h and >8 hours duration*

Winter season	Blizzards		Snow level	Snow precipitation
	No. per season	*Date*	*Inches*	*Inches*
1948-49	1	Jan. 2, 3, 4	31	2.94
1950-51	1	Feb. 12	9	.77
1951-52	2	Dec. 6	6	.63
		Mar. 31	8	.96
1952-53	2	Jan. 14	5	.60
		Feb. 19	10	.95
1953-54	1	Nov. 18, 19	8	.84
1954-55	1	Feb. 19	5	.41
1956-57	3	Nov. 2, 3	15	2.43
		Apr. 4, 5	6	.88
		May 9	7	1.14
1957-58	1	Feb. 27, 28	5	.52
1958-59	1	Nov. 6	5	.56
1959-60	1	Feb. 15, 16	5	.38
1961-62	1	Jan. 8, 9	8	.62
1964-65	1	Jan. 22	4	.50
1966-67	1	Oct. 15, 16	7	1.46
1967-68	1	Nov. 2, 3	5	.52
1969-70	1	Oct. 15	5	.90
1972-73	3	Nov. 12, 13	6	.77
		Jan. 26, 27	7	1.22
		Mar. 27, 28	6	.87
1973-74	2	Oct. 11, 12	9	1.18
		Dec. 18	6	.67
1974-75	1	Mar. 27	5	.97
1975-76	1	Nov. 2	9	1.28
1976-77	1	Mar. 10, 11	5	1.10
Total	27	---	--	--
Average	.9	---	7.7	.97

Table 8.--*Thirty-one-year probability of blizzards during year, Akron, Colo.*

Blizzards (per year)	Years	Probability
	Number	*Percent*
0	11	35
1	15	48
2	3	10
3	2	7
Total	31	100

Table 9.--*Thirty-one-year probability of blizzards by months, Akron, Colo.*

Month	Occurrence	Probability	Water content of snow
	Number	*Percent*	*Percent*
October	3	10	16.9
November	6	19	13.3
December	2	7	10.8
January	5	16	10.7
February	5	16	8.9
March	4	13	16.2
April	1	3	14.7
May	1	3	16.3
Total or average	27	--	12.6

Ground Blizzards

Although of low frequency, serious ground blizzard conditions did occur in northeastern Colorado during the winters of 1948-49 and 1972-73. In these blizzards, very heavy snowfall buried all crop stubble, and air temperatures remained below freezing, which prevented a snow crust from forming. Under these circumstances, the deep loose snow was free to move whenever wind velocities exceeded 20 to 30 mi/h. In both winters cited above, ground blizzards occurred several times within a 40-day span, and emergency measures were needed to rescue motorists and livestock.

SNOWMELT STORAGE IN SOIL

Water from snow can be lost by evaporation, sublimation, blowoff from fields, and runoff from frozen soils. Usually, one or more of these types of water losses occur each season (*11*, *19*, *26*, *27*). For agronomic purposes, the efficiency of snowmelt storage can be defined as the net gain in soil water within the first 6 feet of soil depth from a given water equivalent of snowfall. Data are discussed in this section for snowmelt storage efficiency for three common situations at Akron. Measurement procedures have been previously described (*10*).

In Wheat Stubble

Winter wheat (*Triticum aestivum* L.) is harvested on about 7.5 million acres per year west of the 100° meridian in the central Great Plains. Typically, wheat is grown after fallow in this region. Thus, standing wheat stubble is available as a snowfall catchment for soil water recharge during the first

winter after harvest. Snow catchment involves (1) large fields of undisturbed stubble, (2) the north border (50 to 100 feet wide) of stubble adjacent to planted wheat or pasture, and (3) stubble disturbed by mechanical tillage. Each of these situations affects the potential amount of soil water storage from snowmelt.

The snowmelt storage efficiency in large stubble fields (Rago silt loam) at Akron averaged 55 percent over 20 winter seasons (table 10). During this period, winter precipitation averaged 4.05 inches with an average storage of 2.23 inches per season. Some snowmelt runoff occurred in the springs of 1960 and 1973 or about 8 percent of the years, but the amount of runoff was not great. Snowmelt intake efficiencies ranged from net losses during 3 years to over 60 percent in 9 of 20 years tested. Stubble fields at fall dormancy (mid-October) may contain residual soil water from the previous wheat harvest plus some accumulation of soil water from rainfall received between harvest and fall dormancy.

Table 10.--*Overwinter soil water storage efficiency from snowmelt in undisturbed wheat stubble at Akron, Colo.*

Winter season	Total snowfall[1]	Total winter precipitation[2]	Soil water intake	Snowmelt intake efficiency
	Inches	*Inches*	*Inches*	*Percent*
1959-60	39	3.85	2.12	55
1960-61	28	3.65	2.23	61
1961-62	19	1.73	.45	26
1962-63	21	3.77	1.56	41
1963-64	30	4.70	1.61	34
1964-65	21	2.66	1.23	46
1965-66	21	2.64	1.24	47
1966-67	13	1.38	-.34	-25
1967-68	21	2.30	1.25	54
1968-69	16	1.88	.98	52
1969-70	44	7.65	4.81	63
1970-71	34	4.16	2.70	65
1971-72	6	.80	-.75	-94
1972-73	82	16.54	11.43	69
1973-74	59	6.93	4.22	61
1974-75	24	3.24	1.67	52
1975-76	31	3.26	2.76	85
1976-77	28	3.69	2.80	76
1977-78	14	1.68	-.20	-12
1978-79	39	4.51	2.85	65
Average	30	4.05	2.23	55

[1] As received from mid-October to mid-April.
[2] 90 percent as snowfall.

Stubble also usually harbors some live winter vegetation, like volunteer wheat. Thus, by early spring, after a low snowfall winter, evaporation and consumption may reduce soil water storage to a lower level than that which existed at fall dormancy and thereby results in negative values as shown in table 10.

If we assume an average gain of 2.25 inches soil water from snowmelt in first winter standing stubble plus 1.30 inches from snowmelt the second winter on fall planted wheat, we get a total snowmelt contribution of 3.55 inches of water for wheat production. Wheat yields in the central Great Plains respond at about 4.5 bushels/acre-inch of stored soil water (*11*, *12*). Thus, snowmelt contribution during a 2-year fallow-wheat cycle equates to an estimated 16.0 bushels/acre. During the last 12 years (1968-69), wheat yields at Akron have averaged 36.0 bushels/acre. Snowmelt storage was therefore responsible for about 45 percent of the total yield.

Small patches of undisburbed stubble and north edges of stubble fields usually give high snowmelt storage efficiencies, sometimes more than 100 percent for individual years. Smika and Whitfield (*20*) showed an average of 99-percent snowmelt storage efficiency in four overwinter periods on experimental plots at North Platte, Nebr. Smika and Wicks (*21*) reported a 75-percent snowmelt storage efficiency on other North Platte experimental plots during a later four-season period. Data from Sidney, Mont., (*4*) showed 114-percent snowmelt storage efficiencies on stubble mulch plots. In these instances, extra snow had blown in from surrounding areas. North edges (50 to 100 feet) of large stubble fields often trap additional snow that is transported by wind from open rights-of-way, fall-planted wheat acreages, and pastureland. This additional water is later reflected in higher wheat yields and is especially noticeable in drought years when wheat remains lush along the north border, whereas wheat in the rest of the field exhibits water stress.

Stubble destroyed in the fall by burning or plowing or laid flat by disking seriously reduces the catchment of snow. Smika and Whitfield (*20*), at North Platte, Nebr., showed a 15-percent net loss in soil water storage from winter precipitation by fall incorporation of straw by disking. At Akron, fall disked wheat stubble was responsible for 1-inch less stored soil water during fallow as compared with undisturbed stubble (*9*). The stubble laid flat by fall disking failed to hold blowing snow. Black and Power (*3*) in Montana also showed a 50-percent reduction in overwinter soil water storage by fall disking of wheat stubble as compared with undisturbed stubble.

In Grassland

Snowmelt storage efficiency on ungrazed native grass pasture (Weld silt loam) has been recorded for 12 winter seasons. A net gain of soil water (fall to spring) occurred in 8 of the 12 seasons tested. A light loss of soil water occurred in four seasons of low snowfall whereby evaporation losses from soil exceeded the water gain from snow (table 11). The pasture contained a mixture of short and midgrass species with a dormant-season grass stem height of 3 to 6 inches. During the first seven seasons, winter precipitation averaged 2.95 inches with a soil water storage of 0.91 inch or 31-percent efficiency (table 11). During the next 5 years, winter precipitation was high, averaging 6.59 inches, with a net storage of 2.79 inches or 42-percent efficiency. For all

Table 11.--*Overwinter soil water storage efficiency from snowmelt in ungrazed native pasture at Akron, Colo.*

Winter season[1]	Winter precipitation[2]	Soil water intake	Snowmelt intake efficiency
	Inches	*Inches*	*Percent*
1965-66	2.64	0.80	30
1966-67	1.38	- .22	-16
1967-68	2.30	.50	22
1968-69	1.70	- .08	- 5
1969-70	7.65	3.51	46
1970-71	4.16	1.98	48
1971-72	.80	- .14	-18
1972-73	16.74	7.08	42
1973-74	6.93	3.59	52
1974-75	3.24	1.16	36
1977-78	1.68	- .20	-12
1978-79	4.37	2.31	53
Average	4.47	1.69	38

[1]Winters of 1975-76 and 1976-77 were not measured.
[2]Winter precipitation as occurring from mid-October to late April sampling dates with 93 percent as snowfall.

winter seasons tested, the snowmelt intake efficiency on ungrazed native grass pasture averaged 38 percent. These results are nearly identical to the 39-percent snowmelt intake efficiency obtained by Van Haveren and Striffler (*26*) on short grass prairie near Nunn, Colo. Rauzi (*19*) reported that interseeded midgrass stubble in Wyoming effectively held snow on short-grass rangeland. He also noted that heavily grazed native rangelands were often almost devoid of snow cover during the winter, whereas moderately and lightly grazed rangelands had several inches of snow (*19*). This suggests the possible use of an interseeded cool-season grass like crested wheatgrass (*Agropyron cristatum* L. Gaertn.) in 100-foot-wide strips, oriented east-west, every 300 to 500 feet across shortgrass rangeland. The 3:1 or 5:1 ratio of contributing area to receiving area should help trap sufficient wind-transported snow to significantly increase grass yields and also extend the grazing season by having cool-season and warm-season grasses in the same pasture.

Leeward of Snow Fences

Experimental woodslat snow fences were tested for five winter seasons, 1964-68, to produce snowdrifts of different profile configuration than those observed leeward of a standard highway snow fence 48 inches high with 58-percent

air porosity *(11)*. The fences were constructed of ordinary wood lath oriented vertically and were tested on a level native grass area (Weld silt loam). These fences were 24 and 48 inches high, raised 4 inches above ground level, with the air porosities of 37, 58, 69, 79, and 86 percent. Each fence was 100 feet long and arranged end to end parallel with and 500 feet south of an elevated east-west railroad right-of-way. In this manner, the contributing area was defined. Soil water storage before and after each winter was recorded at 5, 10, 20, 30, 40, 50, and 60 feet leeward of each experimental fence. Snowfall during the 5 years of testing averaged 30 percent below the 24-year norm, whereas the wind-transported snowfall averaged 12 percent below average.

Snowmelt intake efficiency leeward of the fences varied with years but averaged 66 and 70 percent for the 48- and 24-inch-high fences, respectively (table 12). The highest intake was in the winter of 1963-64 at 76 percent as compared with 57 percent for the lowest intake during 1964-65. Differences in snowmelt intake per inch of drift deposit, season to season, were caused by variations in water content in new drifts. These values ranged from 0.098 inch intake/inch snow deposit for the 1967-68 winter to 0.153 inch intake/inch snow deposit for the 1963-64 winter. The data in table 12 are averaged for all porosities because variation of air porosities of the fences caused little difference, ranging from only 0.132 to 0.141 inch intake/inch snow deposit with the 48-inch-high fences and 0.125 to 0.147 inch intake/inch for the 24-inch-high fences. The net gain of soil water from snowmelt averaged 0.133 inch/inch of snow deposit for all seasons and fence variables tested.

There was a high correlation between depth of snow deposit and the amount of stored soil water from snowmelt (fig. 4). This suggests there was very little lateral movement of snowmelt water as is sometimes experienced with frozen soil. In nearly every case, the soil beneath the newly formed snowdrifts was nonfrozen or thawed (if frozen) by upward heat flux after the drift was formed. Thus, the soil storage of snowmelt at Akron, regardless of depth of snow, is quite predictable after the water content of a snowpack is determined.

As noted in the section on "Management of Wind-Transported Snows," 65 percent for snowdrifts deposited with tall wheatgrass snow barriers was close to the 68-percent average snowmelt intake efficiency leeward of all fences tested.

Soil Intake of Rapid Snowmelt

A snowstorm with over 40 mi/h wind velocity, occurring October 14-15, 1966, followed by warm calm weather, presented an opportunity to measure rapid water release from a large, newly formed snowdrift deposited by a woodslat snow fence on Weld silt loam (table 13). This particular storm deposited 7 inches of level snowfall, containing 20.8-percent water content as measured in a quiet, nondrift site. A storm of this type is characterized as a wet blizzard. The data in table 13 show that the 40-inch-high drift was completely melted in 14 days. During melting, the water content of the snow increased from 27 percent to a maximum of 56 percent. Rapid water release did not occur until Oct. 22 when the snowpack reached 44-percent water content.

Table 12.--*Overwinter soil water storage efficiency from snowdrifts deposited leeward of experimental woodslat snow fences at Akron, Colo. (11)*

Winter seasons	Height of fences[1]	Water content of new drifts	Average drift depth[2]	Potential snowmelt	Soil water intake	Snowmelt intake efficiency
	Inches	*Percent*	*Inches*	*Inches*	*Inches*	*Percent*
1963-64	48	19.7	36.6	7.21	4.95	66
	24	19.7	21.0	4.14	3.58	86
1964-65	48	18.4	18.0	3.31	1.95	59
	24	18.4	11.4	2.10	1.16	55
1965-66	48	20.9	19.4	4.05	3.25	80
	24	20.9	15.5	3.24	2.03	63
1966-67	48	24.0	21.8	5.23	2.91	56
	24	24.0	13.5	3.24	2.43	75
1967-68	48	15.4	19.1	2.94	2.00	68
	24	15.4	17.2	2.65	1.57	59
Average	48	19.7	23.0	4.55	3.01	66
	24	19.7	15.7	3.07	2.15	70

[1] Each 48- and 24-inch fence had air porosities of 86, 79, 69, 58, and 37 percent.

[2] Average for all porosities to 60 feet leeward of fence.

Table 13.--*Water release from a new snowdrift deposited leeward of a standard highway woodslat fence 48 inches high and with 58-percent air porosity at Akron, Colo., under rapid melt conditions*[1]

October 1966 (day)	Depth drift	Water content of snow	Unmelted water	Water release
	Inches	*Percent*	*Inches*	*Percent*
15	40	27	10.80	0
16	36	30	10.80	0
17	32	32	10.24	5
18	30	34	10.20	6
19	26	37	9.62	11
20	21	43	9.03	16
22	16	44	7.04	35
24	14	44	6.16	43
26	10	52	5.20	52
27	7	54	3.78	65
28	3	56	1.68	84
29	0	--	--	100

[1] Daily maximum temperatures averaged 59°F Oct. 15 to 29, 1966.
Note: Dashes indicate no data.

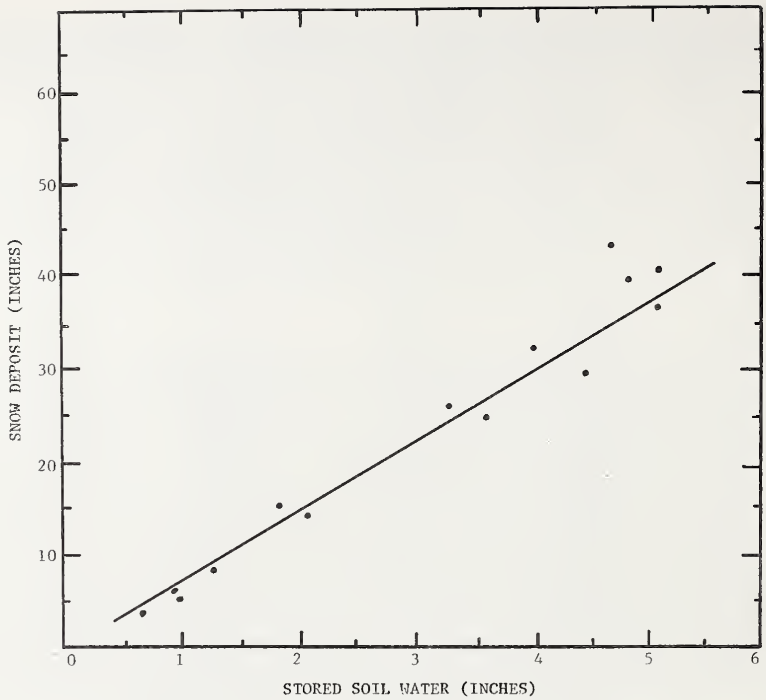
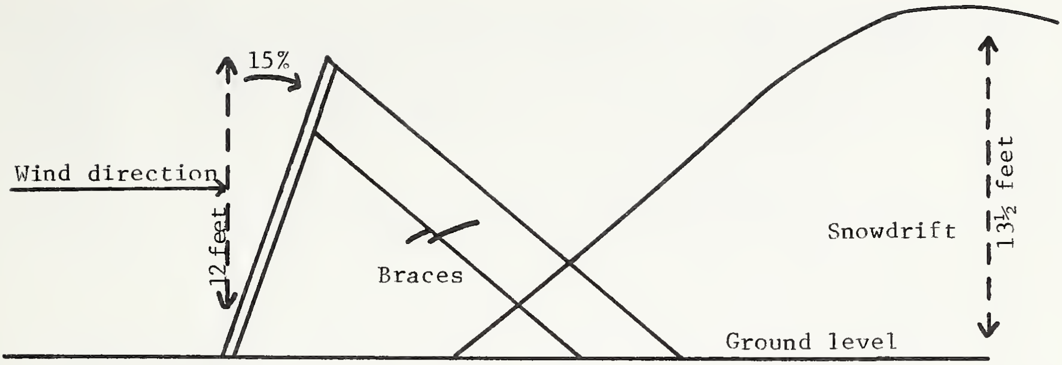


Figure 4.--Correlation of snow deposits leeward of experimental snowfences and and stored soil water from snowmelt at Akron, Colo., 1964-68 (*11*). Points taken from 5, 10, 20, 30, 40, 50, and 60 feet leeward of both 48- and 24-inch-height woodslat snow fences; r = 0.976.

With rapid snow melting on nonfrozen soil, the percent water intake was as high as could be expected. As shown in table 14, snowmelt intake varied from 77 percent where the drift was deepest to 89- and 90- intake where the drift was shallowest. This difference was due to the evaporation exposure time during the melting process. The deep part of the drift was exposed 14 days as compared with only 2 to 4 days for the shallower portion. Nevertheless, when several years of intake data are gathered as occurring over a wide range of climatic conditions, the depth of drift is very well correlated with the amount of intake as previously shown in figure 4.

MANAGEMENT OF WIND-TRANSPORTED SNOW

At the present time (1980), there are few studies on manipulations of blowing snow for specific purposes. Tabler *(23, 24)* has designed an elaborate system of wooden fences 8, 12, and 15 feet in height for highway protection and motorist visibility on Interstate U.S. 80 near Arlington, Wyo. These fences feature 1- by 6-inch woodslats oriented horizontally with 50-percent air porosity. These are built in sections 16 feet long and are arranged end to end for distances of several hundred feet to one-half mile. The fences also slant 15 percent to the leeside of vertical as shown in the following diagram:



With this design, snowdrifts are deposited leeward a distance of 24 to 30 times the height of the fence, and the apex of the maximum drift height is somewhat greater than the height of the fence itself.

With the type of vertical fences used at Akron, the height of the drift can equal but not exceed the fence height. Secondly, the distance of leeward deposition with vertical fences is only 12 to 15 times the height of the fence (*11*, *15*). For maximum snow deposit to the greatest distance, the fences designed by Tabler are the most efficient known, and this type of fence concept, at heights of 3 to 5 feet, needs to be tested for agricultural purposes.

Table 14.--*Variation of snowmelt soil water intake as related to depth of snowdrift under rapid melting conditions. Average of snowdrift sampling leeward of snow fences with 58-, 69-, and 79-percent air porosity*

Distance leeward of fences (feet)	Depth snowdrift[1]	Potential snowmelt	Soil water intake[2]	Snowmelt intake efficiency
	Inches	*Inches*	*Inches*	*Percent*
5	21.3	6.5	5.4	83
10	28.3	8.6	6.9	80
20	31.0	9.5	7.3	77
30	26.7	8.1	6.3	78
40	19.7	6.0	5.0	83
50	9.0	2.7	2.4	89
60	3.3	1.0	.9	90

[1]Measured Oct. 16, 1966, with water content of 30.5 percent.
[2]Soil water samples collected Oct. 30, 1966.

At Akron, systems tested for managing wind-transported snow included: (1) short-height vertical woodslat snow fences, (2) vegetative snow barriers, including crop stubble of sudangrass (*Sudan sudanese*, Piper, Stapf.), and sorghum (*Sorghum bicolor* L. Moench) and perennial tall wheatgrass (*Agropyron elongatum*, Host, Beauv.), and (3) stripcropping.

Wood Fences for Snowdrift Shaping

Tests of 1964-68

Berndt (*2*) found little difference at the Pole Mountain area (8,200-foot elevation) of southeastern Wyoming in the amount of snow trapped between standard highway snow fences when spaced downwind at 175-, 250-, and 325-foot intervals. Martinelli (*17*) observed that 6-foot-high fences raised one foot above ground level produced the maximum snow depth and volume as compared with fences raised 2 and 4 feet above ground level. Fences with 2- and 4-foot gaps formed snowdrifts further away from the snow fences, but less than half the volume of snow was deposited.

The field layout of the woodslat experimental fences at Akron was previously described in the section on "Snowmelt Storage in Soil." During the five test winters, total snowfall averaged only 22.5 inches per season. Of the snowfall events, 39 percent were accompanied by winds of sufficient velocity to cause drifting. Drift-producing storms deposited 63 percent of the total snowfall received and accounted for 71 percent of the total snowmelt.

Snow distribution patterns leeward of various 48- and 24-inch-high fences are given in table 15. The data demonstrate that these fences, even with much below average snowfall, do catch and hold a considerable amount of snow. For example, the average depth of seasonal snow deposition was 72 inches at a point 10 feet leeward of the standard highway snowfence with 58-percent air porosity.

In general, the lower air porosity fences of 37 and 58 percent tended to stockpile snow too close to the fence in relation to the limited volume of wind-transported snow at Akron. The highest air porosity fence at 86 percent had a much better distribution pattern for agricultural purposes but also lower total volume. The largest volume of snow deposited during these test seasons was leeward of the standard highway fence, but the margin over the 69-percent air porosity fence at both heights tested was only slight. The 79-percent air porosity fence had the best combination of volume and distribution pattern. This type of fence is made by removing every other slat from the standard highway fence.

The distribution of soil water intake from snowmelt for these same fence variables followed the same pattern as did the snow deposit (table 16). Average water intake to 60 feet leeward of the 48-inch fences varied from a high of 3.7 inches at 58-percent air porosity to 1.7 inches at 86-percent air porosity.

The shorter 24-inch high fences deposited 68 percent as much snow and 73 percent as much snowmelt intake as did the 48-inch-high fences. This demonstrated that for certain low-volume wind-transportated storms, a tall fence is not necessary.

Table 15.--*Snow deposited leeward of experimental snow fences at Akron, Colo. Average of 5 winter seasons, 1964-68, in which snowfall averaged 30 percent below location normal* (15)

Snowfence height and percent air porosity	Snow deposit at feet leeward 5	10	20	30	40	50	60	Average snow depth to 60 feet[1]	Relative volume	Snow within 20 feet of fence
	Inches							Feet	Percent	Percent
48 inches:										
86	21	26	30	19	13	9	6	16.7	60	53
79	19	33	39	28	17	11	8	21.5	78	52
69	41	56	47	28	16	9	7	25.8	93	61
58	54	72	49	25	16	8	5	27.7	100	67
37	78	58	33	20	10	5	3	23.0	83	73
Average	43	49	40	24	14	8	6	23.0	83	61
24 inches:										
86	20	27	30	19	11	7	6	16.1	58	55
79	23	30	31	17	9	6	5	15.8	57	61
69	40	46	25	12	7	4	4	15.9	57	72
58	49	50	24	12	7	4	4	16.7	60	74
37	65	37	13	8	5	3	3	13.7	49	77
Average	39	37	25	14	8	5	4	15.6	56	69

[1] Average to 10 feet = $\frac{\text{deposit at 5 feet + 10 feet}}{2}$.

Tests of 1969-70

Another test was conducted for two winters, involving 48-inch-high fences with air porosities of 58, 69, 72, 79, and 86 percent. The winters of 1969 and 1970 averaged 31 inches of snowfall per season, about the same as the 24-year average. Drifting occurred in 33 percent of the storms. These storms contributed 50 percent of the total snow and 60 percent of the snow precipitation.

In contrast to data in table 15, the greatest volume and best distribution of snowdrifts were obtained leeward of the 72- and 79-percent air porosity fences (table 17 and fig. 5). About 56 and 49 percent of the snow was deposited beyond 20 feet of the fences at 79- and 72-percent air porosity, respectively, whereas the standard 58-percent air porosity fences only had 28 percent of the snow deposit beyond 20 feet.

Table 16.--*Overwinter soil water intake leeward of experimental snowfences at Akron, Colo. Average of 5 winter seasons, 1964-68, in which snowfall was 30 percent below location normal (15)*

Snowfence height and percent air porosity	Soil water intake[1] at feet distance leeward: 5	10	20	30	40	50	60	Average intake to 60 feet[2]	Relative intake
	Inches							*Inches*	*Percent*
48 inches:									
86	1.8	2.4	2.9	1.9	1.8	0.9	0.4	1.7	46
79	2.8	3.9	4.7	4.3	3.1	1.5	1.4	3.1	84
69	5.1	6.3	6.1	3.9	2.1	1.7	1.0	3.4	92
58	6.6	7.7	7.3	4.3	1.7	1.3	.6	3.7	100
37	7.4	8.2	4.5	3.6	1.5	.8	.4	3.1	84
Average	4.7	5.7	5.1	3.6	2.0	1.2	.8	3.0	81
24 inches:									
86	3.4	3.8	3.0	2.3	1.3	1.3	.9	2.1	57
79	3.1	3.3	3.3	2.0	1.8	1.3	.9	2.1	57
69	4.6	5.1	4.0	1.8	1.3	1.0	.6	2.3	62
58	6.1	6.4	4.1	2.0	.9	.7	.5	2.4	65
37	6.8	7.0	2.2	1.2	.7	.4	.2	1.9	51
Average	4.8	5.1	3.3	1.9	1.2	.9	.6	2.2	59

[1]Sampled within 5 days of drift thawing in the spring.

[2]Average to 10 feet = $\frac{\text{water intake at 5 feet + 10 feet}}{2}$.

To conserve water needed for grass production or young trees for windbreak establishment in the central Great Plains, woodslat fences should have air porosities of 70 to 80 percent for the best combination of snow volume and width of distribution. The 72-percent air porosity fence is made by pulling out every third slat from the standard highway fence.

Wood Fencing for Grass Production, 1966-69

The objective of this experiment was twofold: (1) to measure the distribution pattern of snowmelt on Weld silt loam leeward of a 48-inch-high woodslat snow fence with 72-percent air porosity and (2) to compare the yield and water use efficiency of Russian wildrye grass (*Psathyrostachys juncea*, Fish. Nevski), crested wheatgrass (*Agropyron cristatum* L. Gaertn.), and intermediate wheatgrass (*Agropyron intermedium*, Host, Beauv., var. *intermedium*), utilizing both snowmelt and rainfall (*15*).

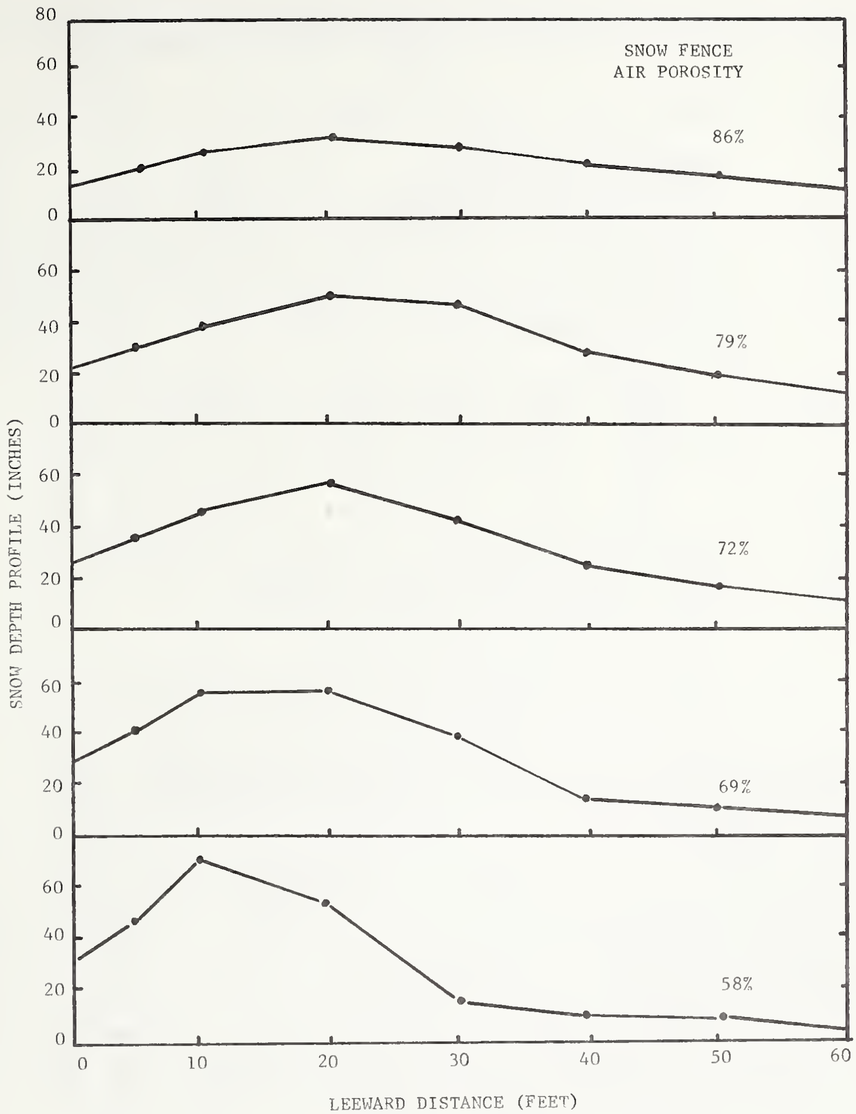


Figure 5.--Profile distribution of snowdrifts leeward of 48-inch-high snow fences, average of 1969 and 1970.

In the fall of 1964, a 48-inch-high snow fence at 72-percent air porosity was installed parallel with and 400 feet south of an elevated east-west railroad right-of-way. The fence, 180 feet long, deposited snow on a 60-foot-wide area where it melted on a freshly plowed Weld silt loam soil during the winter-spring season of 1964-65. The grass species were established during the summer of 1965 on plots 48 by 60 feet. These plots were then divided into 16- by 60-foot subplots and received 0, 25, and 50 lb N/acre in the form of ammonium nitrate each October. Duplicate soil water and plant samples as well as snow measurements, were obtained at 5, 15, 25, 35, 45, and 55 feet leeward of the fences. In addition, plots of Russian wildrye were also established in 1964

Table 17.--*Snow deposited leeward of a 48-inch-high experimental snowfence at Akron, Colo., average of 2 wincer seasons, 1969 and 1970*

Snowfence air porosity (percent)	Snow deposit (inches) at feet distance leeward: 5	10	20	30	40	50	60	Average snow depth to 60 feet[1]	Relative volume	Snow beyond 20 feet of fence
	----------	----------	----------	*Inches*	----------	----------	----------	*Inches*	*Percent*	*Percent*
86	23	28	34	30	23	19	14	24.3	74	59
79	32	40	51	47	29	20	15	33.0	100	56
72	38	47	58	43	25	18	12	33.1	100	46
69	41	55	56	39	14	11	9	29.5	89	41
58	46	71	54	16	11	10	7	26.1	79	28

[1]Average to 10 feet = $\frac{\text{deposit at 5 feet + 10 feet}}{2}$.

on a nearby unprotected nonsnow accumulating area to provide comparison data with and without a snow fence and with rates of 0 and 25 lb N/acre.

At the end of each grass season, the profile distribution of residual soil water leeward of the fence was highly correlated with the net winter gain of water from snowmelt as shown in figure 6. For all four test seasons, available soil water on April 10 averaged 4.76 inches, of which 2.72 inches was from snowmelt. Snowfall precipitation during these 4 test years was 38 percent below the 24-year average. In terms of wind-transported snow, the deposition was 31 percent below the long term average. Snowmelt intake efficiency averaged 64 percent of the snow water deposited. Snowmelt storage for ungrazed native grass north of the snow fence (nondrift area) averaged 29 percent for the same years. The greatest snowmelt intake occurred at 25 feet leeward of the fences.

As shown by figure 7, the average yield of all grasses at all rates of N was well correlated with the total water use at the six sampling distances leeward of the fences. Total water use of all grasses at all rates of N averaged 6.80 inches, which yielded an average 1,660 lb dry mater/acre. Of this, snowmelt contributed about 33 percent to total water use and yield. The highest water use and grass yield occurred at 25 feet leeward of the fence.

Grass yield averaged 1,995, 1,700, and 1,290 lb dry matter/acre for crested wheatgrass, intermediate wheatgrass, and Russian wildrye, respectively (table 18). Nitrogen applications significantly increased yield and water-use efficiency of all three grasses. The average yield increase was 490 and 805 lb/acre for the 25 and 50 lb N/acre rates, respectively. There was no significant change in total water use due to N fertilization.

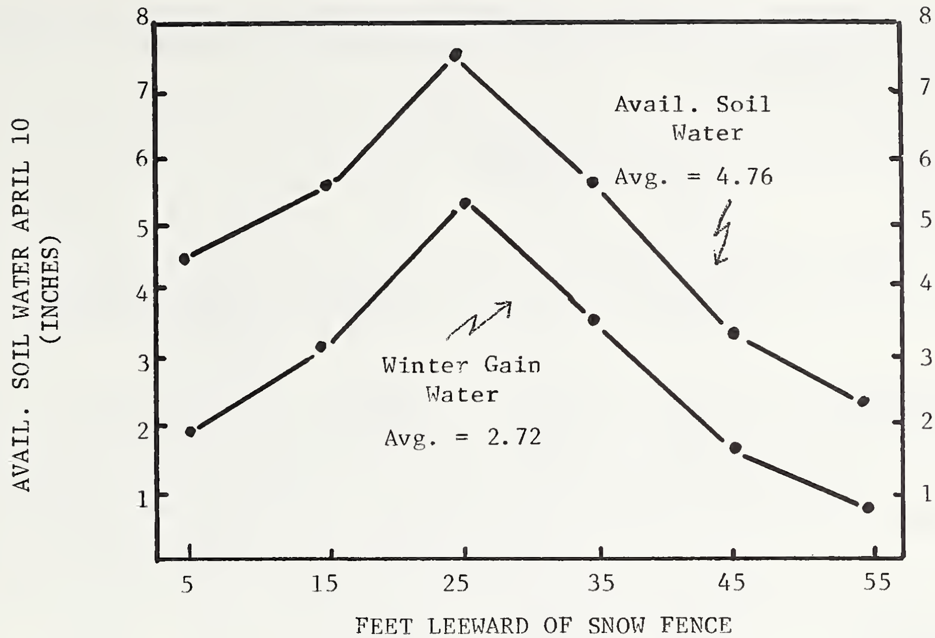


Figure 6.--Over-winter soil water gains leeward of a woodslat snow fence with 72-percent air porosity, Akron, Colo.

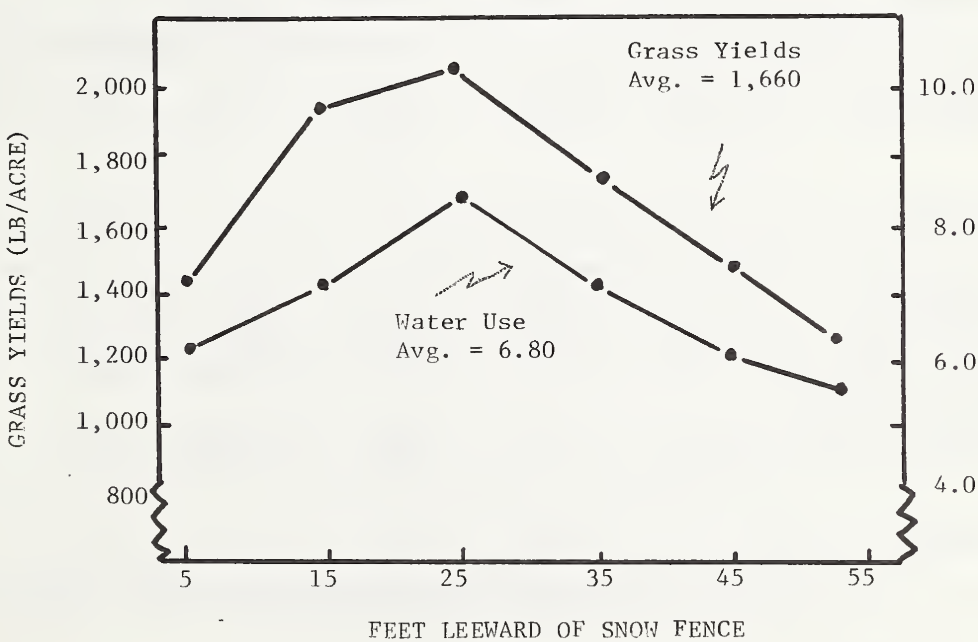


Figure 7.--Relationship of total water use to grass yield leeward of a woodslat snow fence with 72-percent air porosity, Akron, Colo. Average of crested wheatgrass, intermediate wheatgrass, and Russian wildrye plots (*15*).

Table 18.--*Response of grasses to snowmelt leeward of a woodslat snow fence with 72-percent air porosity and to nitrogen fertilization at Akron, Colo., average of 1966-69* (15)

Grass species	Nitrogen rates	Total evapotranspiration[1]	Grass yield	Water-use efficiency	Nitrogen uptake	Protein content
	Pounds/ acre	*Inches*	*Pounds/ acre*	*Pounds/ acre-inch*	*Pounds/ acre*	*Percent*
With snow fence:						
Russian wildrye	0	6.28	850	135	15	11.1
	25	7.64	1,380	180	27	12.1
	50	6.33	1,645	260	36	13.7
Average		6.75	1,290	190	26	12.3
Intermediate wheatgrass	0	7.36	1,270	170	20	9.9
	25	7.32	1,800	245	33	11.6
	50	7.60	2,025	265	39	12.2
Average		7.43	1,700	225	31	11.2
Crested wheatgrass	0	6.21	1,570	255	26	11.3
	25	6.25	1,980	320	35	10.9
	50	6.16	2,430	395	49	12.7
Average		6.21	1,995	325	37	11.3
Average of all grasses	0	6.62	1,230	185	20	10.4
	25	7.07	1,720	250	32	11.5
	50	6.70	2,035	305	41	12.9
Without snow fence:						
Russian wildrye	0	4.78	500	105	10	12.0
	25	4.92	840	170	18	13.4
Average		4.85	670	140	14	12.7
Gain with fence:						
Russian wildrye		2.11	445	20	7	-1.1

[1] Based on soil water consumption plus growing season precipitation.

Water-use efficiency differed considerably with species of grass and N rate, but did not vary with water supply. The maximum difference in water-use efficiency was 135 lb/acre-inch for Russian wildrye with no fertilization as compared with 395 lb/acre-inch for crested wheatgrass fertilized at 50 lb N/acre. The ratio of the difference was 2.9:1. This showed the importance of both plant species and fertilization in maximizing water-use efficiency of snowmelt.

In a single comparison, Russian wildrye leeward of the snow fence averaged 2.11 inches more soil water storage and 455 lb/acre more dry matter production than an adjacent planting of Russian wildrye grass without a snow fence when both were fertilized at 0 and 25 lb N/acre.

Sweet clover (*Melilotus officionalis* (L.) Lam.) or alfalfa (*Medicago sativa* L.) were considered as a way to utilize stored soil water leeward of snow fences more efficiently than some grasses because of deeper rooting system. Morevoer, the good growth characteristics of these legumes could provide an excellent nesting habitat for game birds in the area, particularly pheasants. Secondly, a legume can recharge the soil with nitrogen.

Vegetative Snow Barriers

Stubble of Annual Crops

During 1959 to 1962, a series of double-row plantings of summer row crops were made at Akron on Rago silt loam to determine the characteristics most desirable of the crop stubble to act as snow barriers for depositing snow onto a designated crop target area. Details regarding specific methods and materials for this test are given by Greb (*11*) and Greb and Black (*15*). The results of these tests are given in table 19.

The principle of the narrow, double-row crop stubble barrier is similar to that of wooden fences. The objective is to reduce the speed of wind-transported snow and thereby induce deposition of snow onto a leeward crop target area that is 12 to 15 times as wide as the barrier is tall. Thus, a barrier 2 feet in height should deposit snow across 24 to 30 feet of target area. For the criteria sought, sudangrass (*Sorghum sudanese*, Stapf.) proved superior to various sorghums (*Sorghum bicolor* L. Moench) and corn (*Zea mays*, L.).

The studies conducted here suggest that to effectively deposit and distribute snow, the vegetative barriers should have the following characteristics (*11*, *15*):

- Strong flexible stalks greater than 20 inches in height, but not so tall or top heavy that lodging of stalks from wind or blowing snow would result. Good winter durability is desired.

- Double-row plantings instead of single row to eliminate possible airflow gaps.

- Stalk populations to provide 65- to 75-percent air porosity.

- Spacings between barrier strips (the target area) should be from 37 to 61 feet wide to accommodate common tillage implement widths.

- Orient the parallel barriers at right angles to the prevailing winter winds. In most cases, the orientation is either east-west or east-northeast to west-southwest.

Barriers of sudangrass and Sudax (a forage sorghum) were used in a winter wheat-fallow rotation at Akron during 1960-64, which resulted in an average increase of 6 inches more snow deposition within the barrier system than outside the barriers. Soil water gain from snowmelt and resulting wheat yields for this system are shown in table 20. The soil water recharge averaged 1.5 inches more inside than outside the barrier systems. This extra water increased wheat yields by 230 and 370 lb/acre of grain and straw, respectively, as adjusted for the 10-percent area occupied by the barrier system. Net profit from using this system, assuming today's (1980) wheat prices of $4/bushel, would be $16/acre per season times four seasons, which comes to $64/acre.

During these test years, snowfall averaged 15 percent below normal, but the volume of wind-transported snow was only 4 percent below the 24-year average. The greatest increases in wheat yields were associated with the greatest snow depositions per season in 1960 and 1964.

Disadvantages of using crop stubble as snow barriers include the necessity of annual growing to maturity and then cutting the crop stubble to desired height early in the fall and weed control. Vigorous weed growth on border areas in and next to the barriers in the spring competes with the first one or two rows of crop being grown in the crop target area.

The most optimum types of snowstorms for this system were those with 4 inches or more snowfall at greater than 12-percent water content with wind velocities of 20 to 40 mi/h.

Tall Wheatgrass Snow Barriers, Sidney, Mont.

Although not in the central Great Plains but relative to the Akron data, Aase and Siddoway (*1*) and Black and Siddoway (*4*, *5*) have experimented with tall wheatgrass since the middle 1960's in Montana. They planted tall wheatgrass in double-rows, 36 inches apart, with crop target areas of 30 and 60 feet wide. The grass grew to a height of 4 to 5 feet. A relatively dense leafy growth developed to 1 foot above ground level with seed stalks extending higher. As a perennial grass, it proved quite durable year-to-year and was very effective in trapping and holding snow. Air porosities for the double-row barrier ranged from 65 to 70 percent, about ideal for the purpose intended. The grass barrier system at Sidney, Mont., effectively reduced windspeeds leeward of the barrier an average 80, 60, 40, and 30 percent at distances of 5, 11, 16, and 23 feet, respectively.

During one 4-year study (*4*), average depth of leeward snow gradually decreased from 25 to 17 inches across each 30-foot crop target area, and from 21 to 8 inches across each 60-foot target area. In both cases, snow depth also

Table 19.--*Rating of crop stubble as potential snow barriers, Akron, Colo., during 1959-62*

Crops tested	Lodging potential[1]	Air porosity[2]	Stalk flex	Ratings
		Percent		
Sudangrass	Slight	65-75	Flexible	Very good.
Forage sorghums:				
Sudax	Some	70-75	Slight flex	Good.
FS-1A	--do--	70-75	Rigid	Do.
Coes	Variable	70-75	Slight flex	Fair.
Grain sorghums:				
RS-501	--do--	70-75	--do--	Do.
Reliance	Moderately high	75-85	--do--	Fair to poor.
RS-608	High	75-85	Rigid	Poor.
Midland	--do--	75-85	--do--	Do.
Corn	Variable	80-85	--do--	Do.

[1] Summer drought in 1959 and 1960 resulted in stalk rot of grain sorghums and corn, which enhanced lodging and poorer performance. Sunflower was not tested.

[2] When grown in double rows 14 inches apart.

Table 20.--*Grain and straw yields of winter wheat and soil water gains leeward of sudangrass-forage sorghum snow barriers at Akron, Colo., average of 1960-64 (11, 15)*

Distance leeward of barriers (feet)	Change in soil water from fall to spring as compared with check	Grain yield	Straw yield
	Inches	*Pounds/acre*	*Pounds/acre*
5	+0.25	1,320	2,600
10	+2.10	1,700	3,400
15	+2.20	1,700	3,500
20	+1.90	1,640	3,300
25	+1.75	1,550	3,250
30	+1.40	1,530	3,130
35	+1.00	1,500	3,100
Average	+1.50	1,560	3,190
Check	0	1,330	2,820

tended to increase immediately adjacent to the windward side of each barrier strip. The average snow depth was increased about 15 to 18 inches within the 30- and 60-foot target area above that of the snow deposition outside the barrier systems.

Black and Siddoway (*5*) also showed yield increases of continuous and fallowed spring wheat (*Triticum vulgare* Vill.) and winter wheat within the barrier system spaced with crop target areas 50 feet wide as optimum width. There was enough extra water (2 inches) and yield gain of fertilized continuous wheat that fallow could generally be eliminated with the improved snow management.

Tall Wheatgrass Snow Barriers, Akron, 1974-77

Tall wheatgrass barriers were tested at Akron with crop target areas of continuously grown forage crops (*12*, *13*). The forages included winter wheat, winter rye (*Secale cereale* L.), sudangrass, and millet (*Setaria italica* L.). Tall wheatgrass was seeded in June 1972 in 14-inch double-rows spaced 37 feet apart on summer fallowed Rago silt loam. The planting was kept free of weeds with herbicides and cultivation and attained maturity in 1973 such that is was ready to function as a snow barrier for the winter of 1973-74 and thereafter. About a 75-percent stand of tall wheatgrass was obtained in each of the two rows per barrier strip. The forage crops grown on fallow in 1973 were not included for analysis because snow deposition did not occur until the following winter. The four forage crops were successfully grown continuously inside and outside the barrier system and also on fallow outside the barriers during 1974-77. These crops received 35 pounds N/acre applied each fall before the snow season.

There was one snow storm per season of the wet blizzard type that significantly contributed extra snowmelt to soil water recharge in the barrier crop target area as compared with that deposited outside the barriers (table 21).

Table 21.--*Significant snowstorms contributing snowmelt leeward of tall wheatgrass snow barriers at Akron, Colo.*

Winter season	Date of storm	Water equivalent deposited at feet leeward of barriers			Average deposit	Snowmelt intake	Snowmelt intake efficiency
		0-12	12-24	24-36			
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Percent*
1973-74	Dec. 18, 24	2.80	2.00	1.35	2.05	0.95	46
1974-75	Mar.27	3.88	2.55	1.30	2.58	1.85	72
1975-76	Nov. 20, 21	5.50	3.25	1.75	3.50	2.25	64
1976-77	Mar. 10	4.82	3.59	2.81	3.75	2.68	71
Average		4.25	2.85	1.80	2.97	1.93	65
Pct. total		48	32	20			

Although the blizzard of March 10, 1977, was clocked at greater than 80 mi/h, the airborne snow was very efficiently deposited in the barrier system. Tightly packed snow was 15 inches deep along the leeward northern third of the target area strips and tapered to 7 inches deep across the southern portion of the crop target area. There was no other snow stopped or held by crop stubble at the Station and surrounding area because of the extreme wind velocity. Thus, the tall wheatgrass barriers proved remarkably effective under extreme blizzard conditions.

The snowmelt deposit averaged 2.97 inches per season of which 1.93 inches was stored in the soil for later consumption by the forage crops. Snowmelt intake efficiency averaged 65 percent for all seasons. The low value of 46-percent efficiency in the winter of 1973-74 occurred because of frozen soil conditions, which enhanced some snowmelt runoff. The snow and snowmelt distribution averaged 48, 32, and 20 percent leeward at distances of 0 to 12, 12 to 24, and 24 to 36 feet (table 21, fig. 8). Across the crop target area, the average snow depth varied from 17 to 6 inches. Snow depth also increased on the adjacent windward side of each barrier. Snowmelt water in the soil was highly correlated with snow depth.

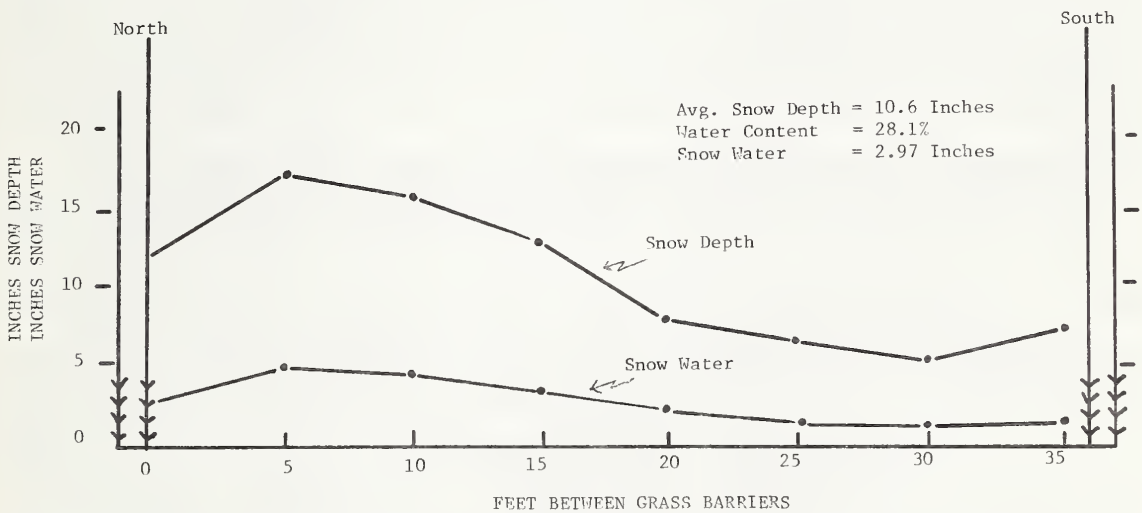


Figure 8.--Snow depth profile between tall wheatgrass barriers resulting from one major snowstorm per season, 4-year average, 1974-77 (*12*, *13*).

Because of increased water supplies within the barrier systems, forage yields were increased in each of the 4 years tested. The yield gain averaged 1,065 lb dry matter/acre per season (table 22), or was 43 percent greater than the yield of forages grown outside the barriers. The net gain in yields averaged 490 lb/acre for 1974 and 1975 and 1,640 lb/acre in 1976 and 1977. Yields were increased an average 550 lb/acre-inch of soil water derived from snowmelt. The yield of forage grown on fallow was just about double that grown continuously without barriers.

Although there were production differences between the four forage crops, the gain in yield resulting from snowmelt was similar (table 23). Winter rye

Table 22.--*Average yield of 4 forage crops*[1] *by years with and without a tall wheatgrass snow barrier system at Akron, Colo. (12, 13)*

Crop year	Forage yield: No barrier--continuously cropped	Forage yield: Snow barrier continuously cropped[2]	Forage yield: No barrier--crop fallow	Yield gain barrier area	Snowmelt yield efficiency[3]
	Pounds/acre				*Pounds/acre-inch*
1974	2,480	2,840	4,570	360	380
1975	2,975	3,595	5,490	620	335
1976	2,100	3,710	4,020	1,610	715
1977	2,365	4,035	5,245	1,670	625
Average	2,480	3,545	4,830[4]	1,065	550

[1] Combined dry matter yield of winter rye, winter wheat, sudangrass, and hay millet.
[2] Yield reduced 10 percent to compensate for land area occupied by grass barriers.
[3] Yield gain barrier area divided by snowmelt intake (see table 21).
[4] One crop every 2 years; thus, annual yield averaged 2,415 lb/acre.

Table 23.--*Yield of individual forage crops with and without a tall wheatgrass snow barrier system at Akron, Colo., average of 1974-77*

Forage crop[1]	Forage yield: No barrier--continuously cropped	Forage yield: Snow barrier continuously cropped[2]	Forage yield: No barrier--crop fallow[3]	Yield gain barrier area
	Pounds/acre			
Winter rye	2,840	3,940	5,140	1,100
Winter wheat	2,300	3,490	5,100	1,190
Hay millet	2,610	3,610	4,845	1,000
Sudangrass	2,125	3,135	4,230	1,010

[1] Varieties included Tetra Pectus rye, Centurk wheat, Leonard millet, and Piper sudan.
[2] Yields reduced 10 percent to compensate for land area occupied by grass barriers.
[3] Average annual yield equals one-half of values shown.

produced the most dry forage for all systems at 3,975 lb/acre, and sudangrass produced the least at 3,165 lb/acre. Winter wheat and hay millet produced 3,630 and 3,690 lb/acre per season during the 4 test years, respectively.

Tall Wheatgrass Snow Barriers, Akron, 1979

During 1977, the tall wheatgrass barriers began to deteriorate because of severe drought and exhaustion of deep soil water reserves. Therefore, the plot areas within the barriers were fallowed in 1978 to help revitalize the grass with soil water recharge. Despite much below average snowfall during the winter of 1977-78, there was an abundance of rain and snow beginning August 1978 and continuing through all of 1979. The tall wheatgrass barriers thereby recovered remarkably well, regaining vigor in the crown area and producing numerous tillers and seedstalks 4 and 5 feet in height by late June 1979. Winter wheat was planted in September 1978 for the 1979 harvest.

Although there was good snowfall during the late winter and spring of 1979, wind-transported snow accumulated only on the north one-third (about 12 feet wide to a depth of 6 inches) of each crop target area. Precipitation was highly efficient from early spring to harvest with little evaporation or runoff. By wheat harvest, total water use averaged 18.37 inches for the entire experimental area, which was 2.5 inches above the average for recent years at Akron. Total water use was 19.42 inches inside the barrier system and 17.32 inches outside the barrier area.

Wheat yields inside the barrier averaged 3,650 lb/acre (60.9 bushels/acre) as compared with 3,100 lb/acre (51.7 bushels/acre) outside the barriers (table 24). Yields also averaged 3,500 lb/acre (58.3 bushels/acre) for the residual rye and wheat plots as compared with 3,240 lb/acre (54.0 bushels/acre) for residual hay millet and rye.

Subsampling within the barrier crop target area showed grain yields of 70.4, 57.9, and 54.4 bushels/acre for the north, middle, and south portions of the cropping area, respectively. The pattern of straw yields was nearly identical to that of the grain yield. In all cases, the yields of grain and straw reflected the available water supply.

Total wheat dry matter production within the barrier system exceeded that outside the barriers by 1,120 lb/acre. In addition, total dry matter yield on the residual rye and wheat plots exceeded that for residual hay millet and sudangrass by 1,000 lb/acre. Although water-use efficiencies were very high for all treatments, there was no difference between the efficiencies inside and outside the barrier system, partly because of a higher-than-normal total precipitation.

Experimentation with tall wheatgrass barriers at Akron revealed a number of advantages and disadvantages as follows:

<u>Advantages of Tall Wheatgrass Barriers</u>

- Barriers will efficiently trap and hold wind-transported snow. The best results in the central Great Plains occur from wet blizzards, defined here as greater than 4 inches snowfall with

Table 24.--*Yield of winter wheat inside and outside a tall wheatgrass barrier system at Akron, Colo., wheat harvested July 27, 1979*

Previous cropping[1]	Grain yield	Straw yield	Total dry matter	Total water use[2]	Water-use efficiency[3]
	Pounds/ acre	*Pounds/ acre*	*Pounds/ acre*	*Inches*	*Pounds/ acre*
Inside barriers:					
Winter rye	4,040	6,770	10,810	20.61	525
Winter wheat	3,620	6,520	10,140	20.98	485
Hay millet	3,450	5,760	9,210	18.15	505
Sudangrass	3,475	6,125	9,600	17.93	535
Average	3,650	6,290	9,940	19.42	510
Outside barriers:					
Winter rye	3,280	5,935	9,215	17.25	535
Winter wheat	3,065	5,755	8,820	17.57	500
Hay millet	2,920	5,330	8,250	17.37	475
Sudangrass	3,125	5,815	8,940	17.11	520
Average	3,100	5,720	8,820	17.32	510
Gain with barriers	550	570	1,120	2.10	0

[1] All as forage crops; rye and wheat harvest in early June 1977, hay millet and sudangrass harvested in mid-August 1977; all plots were summer fallowed in 1978.

[2] Soil water consumption plus crop season precipitation.

[3] Total dry matter divided by total water use.

greater than 14-percent water content and with windspeeds above 35 mi/h. Crop yields are increased substantially most seasons inside a barrier system.

- Barriers are also effective in reducing evaporation during the warm season because of less average wind velocity across the target area between parallel barriers. This was especially pronounced after the heavy rains received during August 1978. This observation agrees with the findings of Aase and Siddoway (*1*).

- Tall wheatgrass barriers have perennial use value and do not

require annual installation as with the crop stubble of sudan-grass and sorghums.

- Barriers protect soils from wind erosion and also protect young crop plants from wind desiccation and soil abrasion.

- Barriers can offer quick farmstead protection from drifting snow until perennial woody species of a windbreak become established.

- Barriers may have a use in the rehabilitation of mine spoils.

Disadvantages of Tall Wheatgrass Barriers

- All tillage is fixed in a given direction. On long downhill slopes, this may increase water erosion potential.

- Grass barriers require regular weed control maintenance in the central Great Plains.

- Snow deposit favors the north half of the target area, which results in uneven height of the crop being grown.

- Grass barriers are vulnerable to degradation by drought and hail. The crop target area may need to be fallowed about every fourth year to recharge the soil water supply and thereby revitalize the barrier strips.

The overall results of experimentation with tall wheatgrass barriers at Akron and in Montana suggest that barrier systems would be best adapted where snowfall expectancy exceeds 28 inches per winter and where wind-transported snow is a fairly common occurrence. Within U.S. boundaries, this would include much of the northern Great Plains from Montana, North Dakota, and western Minnesota, the western two-thirds of South Dakota, the western third of Nebraska, extreme northwestern Kansas, southeastern Wyoming, and northeastern Colorado. Although this system is being used on 40,000 acres of cropland in eastern Montana and western North Dakota, it remains largely noncommercial elsewhere.

Stripcropping for Snow Retention

During droughts in the northern Great Plains earlier in this century, some land operators noticed that the north edge of crops were often healthier and less prone to wind erosion and water stress than the rest of the field. It was thought that by increasing the number of north edges, by stripcropping, part of the danger of crop failures and soil loss would be eliminated. Secondly, the capture of extra wind-transported snow in crop stubble, usually wheat, enhanced crop conditions along these north edges. Thus, stripcropping became a widely accepted practice for wind erosion control in the northern Great Plains where wind-transported snow is also a major feature of the winter season.

In the semiarid central Great Plains, stripcropping is used on only about 25 percent of the dry cropland, primarily on sandy land susceptible to wind erosion. In the southern Great Plains, stripcropping is seldom used. One of the complaints of farmers concerning stripcropping in the central and southern Great Plains cropland is that along the edges of stubble strips, grasshoppers are responsible for killing wheat several drill rows into adjacent planted strips. This author has tested this concept near Akron and found that grasshoppers were seldom the cause. Most operators permit weeds to grow in the stubble after wheat harvest. The weeds on the edge of stubble strips become very large and extend roots 4 to 10 feet into the fallow strips intended for wheat and thereby sap most of the available water and nitrogen. If operators prevented this weed growth, by undercutting tillage with V-blade sweep tillage or with herbicides, much of this strip edge problem would be solved.

Based on the known characteristics of snowfall in the semiarid central Great Plains plus the available equipment and technology, there is little reason that alternate wheat and fallow strips, 100 to 150 feet wide, would not be successful for the area north of the Arkansas River and west of the 100° meridian. It is disheartening to see 80 percent of the snow, containing 0.7 to 1.3 inches of water, being swept off large planted wheatfields once or twice in a winter season. This water is worth 4 to 7 bushels of wheat per acre-inch and 8 to 14 bushels of grain sorghum per acre-inch (*13*, *21*). This would translate into \$16 to \$28/acre for wheat at \$4/bushel for wheat, and \$12 to \$21/acre for sorghum at \$2.70/hundredweight.

In 1958, stripcropping patterns were initiated at Akron to determine feasible ratios of contributing area to receiving area for snow retention. The original design included a 4:1 and 2:1 ratio of planted wheat to grain sorghum stubble. The sorghum strips were placed south of each planted wheat strip. This design included only four rows of sorghum stubble (14 feet wide). These proved to be too narrow for snow retention within the strips and too wide to act as barriers for leeward deposition as tested during the winters of 1958-60.

The sorghum strips were redesigned in 1961 with 2:1 and 1:1 ratio of contributing area to receiving area. The strips included 8 rows (28 feet wide) and 12 rows (42 feet wide). Observations and photographs were made of this snow retention scheme during the winters of 1962-64. Some of the drift patterns are shown in figure 9 for various types of wind-transported snowfall. In general, a minimum of 8 rows, and preferably 12 rows, of sorghum stubble (3½ feet between rows) best retained the snow within the strips for 2- to 4-inch wind-transported snowfall events. New snow generally sifted past the north one or two rows before accumulation began, which reached maximum depth after the fourth row. Accumulated snow usually melted away before new snow arrived. Observations indicated that a minimum sorghum population of 18,000 stalks per acre and 12-inch stubble height was required to effectively retain the snow under average wind-transport conditions. Retention was also best when the water content of new snow exceeded 12 percent. There was sufficient extra snowmelt retained with the sorghum stubble strips that sorghum could be grown every year and yield 18 to 22 bushels/acre without need of fallow. Without stripcropping at Akron, continuous and fallowed sorghum has yielded about 10 and 26 bushels/acre, respectively.

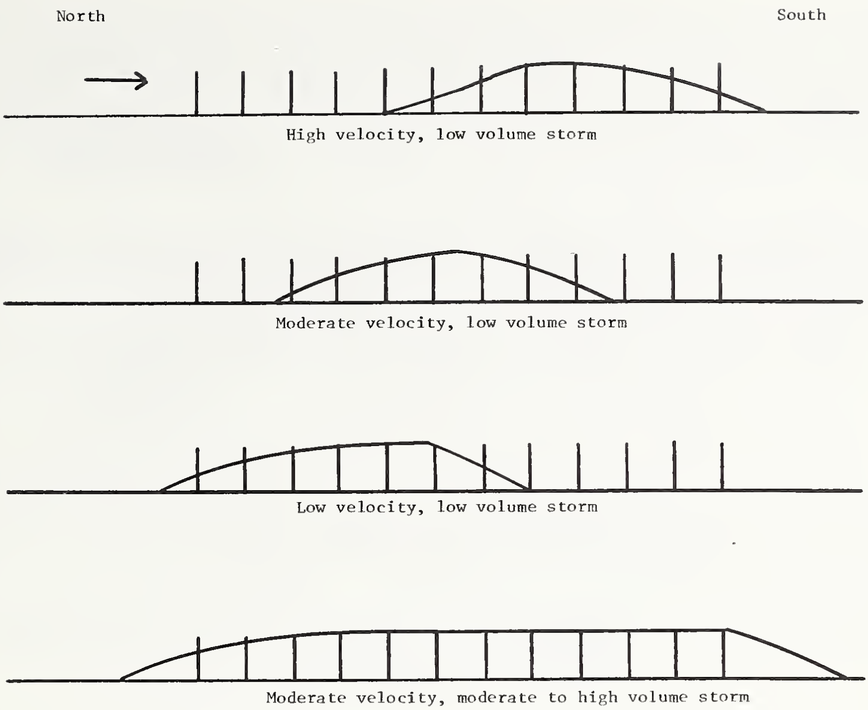


Figure 9.--Snowdrift position within a 12-row sorghum stubble strip observed at Akron, Colo., during winters of 1962-64. (Low volume storm about 2 inches snowfall: high volume storm, 4 inches snowfall or more.)

As with wood fencing and vegetative barriers, it seems that the potential for designing stripcropping systems for snow management is greatly underestimated and underutilized. In nearly all cases, snow retention on the farm is more by accident than by intent.

Windbreaks

For over 60 years in the Great Plains, conservation agencies have advocated increased use of multirow and single-row plantings of trees and bushes to moderate the microclimate near homesteads, around livestock feed areas, and on croplands. In the northern Great Plains, the modern trend has been to use multirow windbreaks adjacent to the homestead and single-row plantings, spaced parallel at 40 rods, across cropland for windspeed reduction and snow spreading (*7*, *8*). In the central and southern Great Plains, farmstead windbreaks are common, but windbreaks across croplands are rare. A few are used in favorable sites for wildlife habitat. Greb and Black (*14*) found that root extension of large bushes and trees at Akron would sap soil water and nutrients to distances of up to four times their height and thereby reduce crop yields within 30 to 100 feet of a windbreak.

In recent years, windbreaks have declined throughout the Great Plains. The rapid consolidation of land ownership has significantly reduced the number of on-site farm families and, thus, windbreak abandonment. These abandoned plantings deteriorate and are subsequently removed. The advent of the center pivot irrigation system has also been responsible for windbreaks being torn out where they interfere with the circular movement of sprinkler pipes.

Windbreaks do influence the movement and retention of wind-transported snow. The trapping of snow within windbreaks is necessary in the semiarid central Great Plains to maintain a viable windbreak as rainfall by itself is insufficient. Snow retention with windbreaks is a function of the density and width of the windbreak in combination with the wind velocity and snow load of incoming storms. Some typical snow deposition patterns formed by various windbreaks in the northern and central Great Plains are diagramed in figure 10.

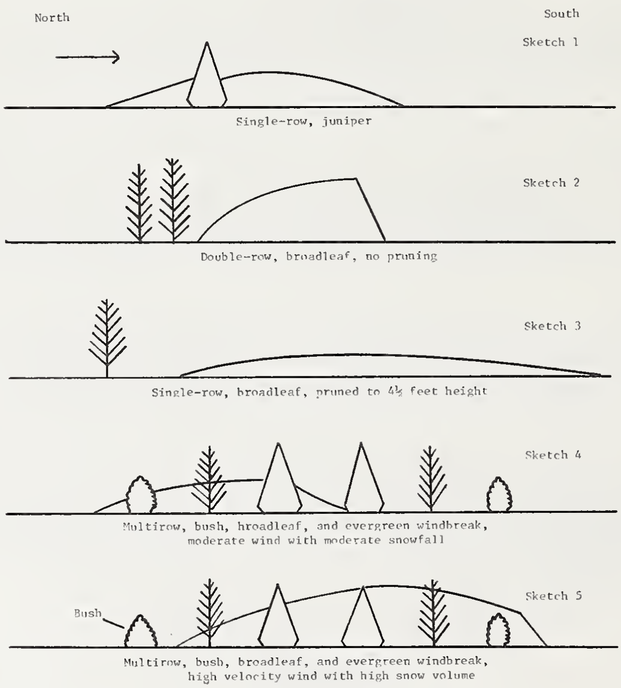


Figure 10.--Typical snow deposition resulting from various types of windbreaks in the northern and central Great Plains (7, *8*).

In the first sketch, Rocky Mountain juniper (*Juniperus scopulorum* Sarg.), a dense evergreen, normally causes about 20 to 25 percent of the snow to deposit on the windward side and the remainder of the snow to deposit leeward to distances up to five times the height of the trees. Sketch 2 shows a common problem in the northern Great Plains in which an unpruned double-row of broadleaf trees, usually Siberian elm (*Ulmus pumila* L.) or Russian-olive (*Elaeagun angustifolia* L.) forms drifts up to 8 and 10 feet deep but only 25 to 30 feet wide (7, *8*). On sloping land, these huge drifts would cause soil erosion upon melting and would delay spring tillage and planting until the area is dried out.

The more optimum type of snow spreading for agricultural purposes is given in sketch 3, which depicts a single row of broadleaf trees pruned to 4½ feet from base level. This permits sufficient air porosity to form a low profile and a widespread snowdrift. The drift usually does not form until it is 10 to 15 feet leeward of the windbreak. This type of drift can be valuable as soil water recharge on cultivated land (7).

Sketches 4 and 5 show that multirow windbreaks are self-feeding mechanisms by the nature of the snow capture within the windbreak. High volume snow blizzards have occurred three times since 1955 in the Akron area. In each case, the snow almost buried evergreen trees 10 to 12 feet tall. When the snowdrift ripened (settled), the weight of snow snapped off the lower tree limbs. Damaged trees were then vulnerable to invading disease and insects.

Single and double-row windbreaks at key locations could be used to a much greater extent in the Great Plains for the protection of highways and railroads from periodic blockage by deep snowdrifts. For example, on highway U.S. 34 from Akron to Wray, Colo., a distance of 54 miles, there are several locations, of only 1,000 to 1,500 feet length each, which cause the highway to be closed from 1 to 3 days after a large blizzard. Strategic tree plantings 200 feet north and parallel to the highway at these locations might solve this traffic disruption problem. Almost any east-west highway in the region has similar problems.

DISCUSSION AND CONCLUSIONS

In the semiarid central Great Plains north of 39° latitude, average annual snowfall exceeds 28 inches, which is equivalent to 3.3 inches precipitation. This snowfall can be a more important part of the water budget needed for crop and rangeland production because of the high efficiency with which snowmelt enters the soil; however, about one-third of the snowfall is blown off planted wheatfields, fall-plowed fields, and heavily grazed pastures during wind-transport situations. To date, there is little or no commercial management to trap and retain snow in place other than random large fields of crop stubble and isolated windbreaks.

Data given here suggest that some of the wind-transported snow can be manipulated, with various obstructions, for water conservation. Short-height wood-slat snow fences of 70- to 80-percent air porosity can cause significant quantities of wind-transported snow to be deposited leeward 12 to 15 times the height of the fence. The extra snowmelt can be used for two-row windbreak establishment, better growth of fertilized grasses, or limited protection along farmstead roads and around buildings. Tabler (*23*, *24*) has shown that the efficiency of fencing can be greatly improved by changing the slat orientation from vertical to horizontal and tilting the fence 15 percent to the leeward side. Narrow vegetative snow barriers of crop stubble and tall wheatgrass were positive in increasing crop yields by successfully depositing windblown snow onto crop target areas. The vegetative barrier system requires a much more intensive type of field culture than the large block farming in use today.

Greater use of 100- to 150-foot-wide strips of various crops at a 90° angle to prevailing storm winds would greatly reduce snow water losses over very wide geographic areas. Shortgrass rangeland could also include strategically placed 60- to 100-foot-wide strips of cool-season midgrasses to trap blowing snow. These could be placed every 300 to 500 feet across rangeland to trap the wind-transported snow. Additionally, these strips might lengthen the grazing season for livestock. With tree species currently used, it is doubtful that single-row field windbreaks for snow deposition purposes will find a useful place in the central Great Plains because of root sapping of the trees adjacent to cropland. Secondly, absentee ownership and rental of large quantities of dryland alone are not conducive to the installation and maintenance of extensive windbreak plantings.

As water conservation becomes more sophisticated, all water resources, including snow, will demand more intensive and beneficial use in order to provide the projected needs of food, fiber, and domestic animal feed for our society.

More intensive research is needed to develop the best snow management practices for agricultural lands. There is also a need to apply to more areas those practices which have already been developed.

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